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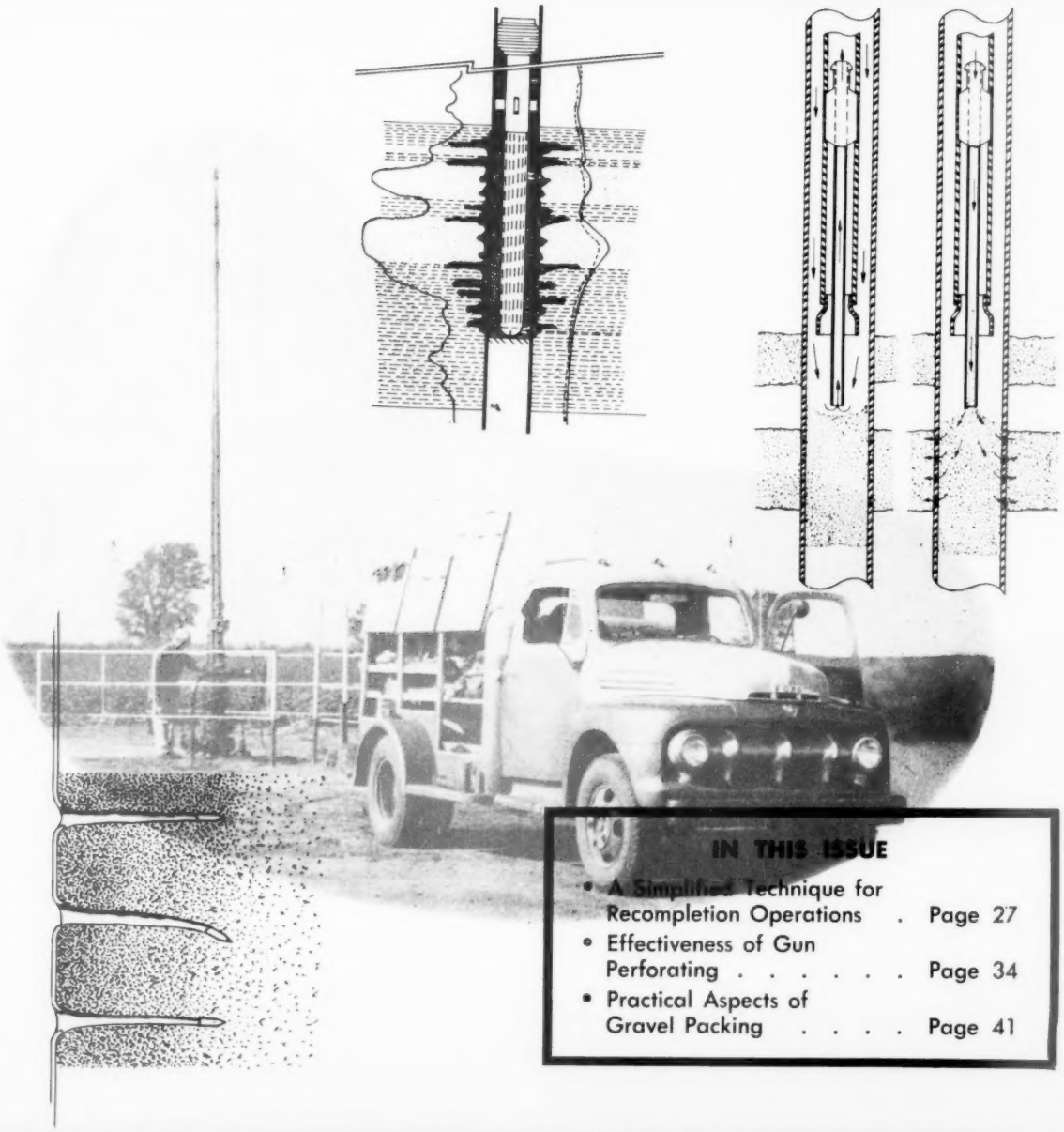
Petroleum Technology



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- Practical Aspects of Gravel Packing . . . . Page 41

JANUARY, 1954

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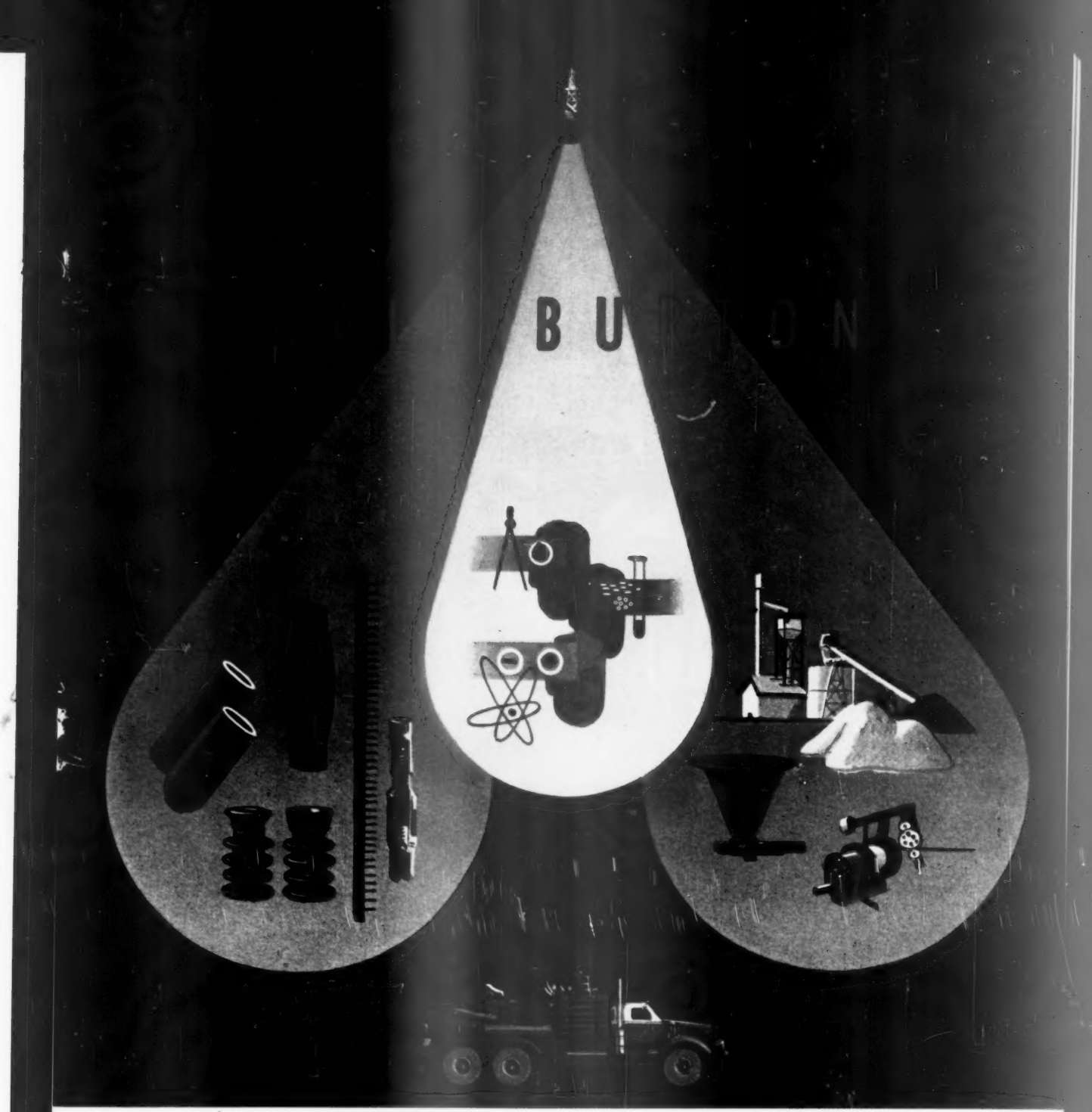

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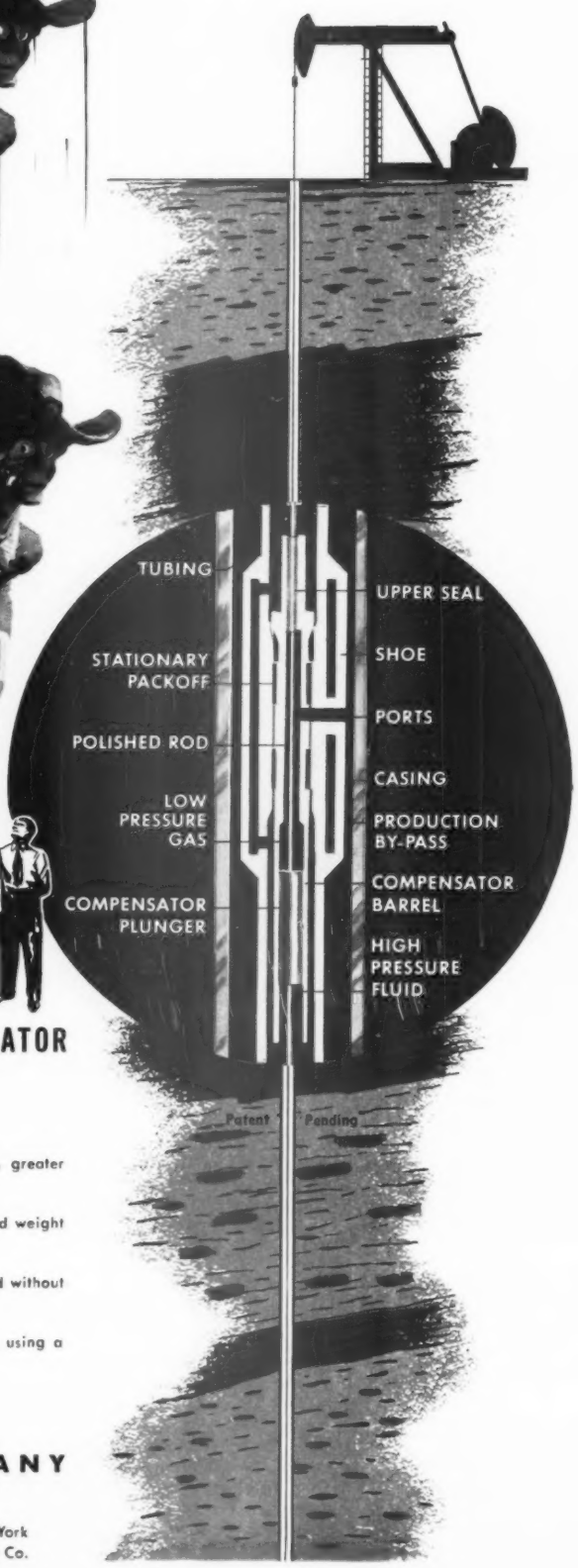

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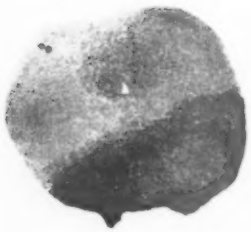

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Vol. VI JANUARY, 1954 No. 1

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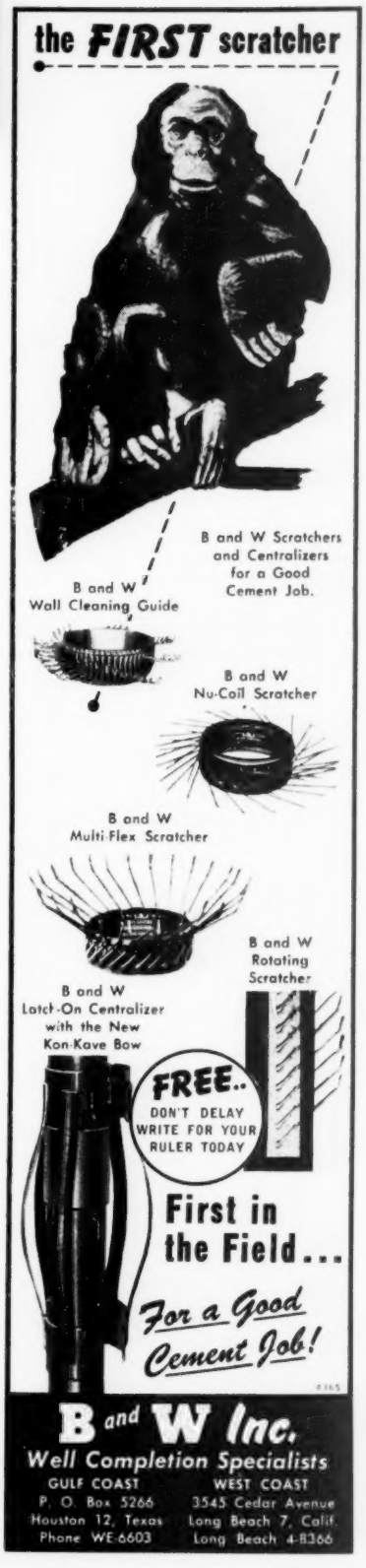
JOURNAL UNDERGOING CHANGES

With this first issue of 1954 you may note a few of many changes planned to make your JOURNAL OF PETROLEUM TECHNOLOGY a more readable and better looking publication. Hill and Christopher Advertising Agency of Los Angeles and the new staff of the magazine are undertaking the job of giving it a complete face-lifting. No longer is your magazine divided into three distinct sections; consecutive numbering of the pages throughout each issue starts this month. The typographical layout of the transactions, the column width, and the type face used are new in this issue. A change in the cover design is forthcoming, along with other improvements throughout the magazine. We want to make JOURNAL OF PETROLEUM TECHNOLOGY as attractive and easy to read as possible — the professional magazine of the petroleum engineer.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October 17-20, 1954

San Antonio to Be Site of Next Petroleum Branch Fall Meeting

By JOE B. ALFORD

A record breaking attendance of 2,400 at the 1953 Petroleum Branch Fall Meeting in Dallas highlighted the fact that only a very limited number of cities in the oil country have adequate facilities for conducting the annual Fall Meeting. The 1954 meeting, which had been scheduled over a year ago for San Antonio, is a case in point. After the Dallas meeting it was thought necessary to re-examine the adequacy of facilities in San Antonio, and this revealed that the city does not have two meeting rooms now large enough to conduct the meeting on the basis of two concurrent technical sessions as has been customary in recent years. The conclusion was reached that the only way in which the meeting could be held in San Antonio is to hold *three* concurrent technical sessions. This constituted a question for decision by the Branch Executive Committee, which voted by a considerable majority to hold the meeting in San Antonio on the basis of three concurrent technical sessions. However, in taking this action, the Committee voted only on the 1954 meeting, and did not endorse the three session plan as a permanent policy. The previously reserved dates of October 17-20, Sunday through Wednesday, were confirmed.

Members and guests who attended the 1949 Branch Fall Meeting in San Antonio invariably recall it as one of the most enjoyable meetings we have had in recent years. Preliminary plans indicate that the 1954 meeting will be even better in several ways. The Southwest Texas Local Section in Corpus Christi will be host to the meeting. Chester L. Wheless, La Gloria Corporation in Corpus Christi is Section Chairman, and R. K. Guthrie, Seeligson Engineering Committee is Vice-Chairman for San Antonio. Along with other Section officers, they are now forming plans for committees and arrangements to execute the meeting.

Technical Program

Concurrent technical sessions will be held in the ballroom of the Gunter Hotel, the Roof Garden of the Plaza Hotel, and one of the downtown theaters. Each of these can comfortably seat about 700 persons, and they are all located within a few blocks of each other. Preliminary plans are to conduct three concurrent technical sessions on Monday, Tuesday, and Wednesday mornings, with only two concurrent sessions each afternoon. This will require the presentation of about 50 papers in 15 technical sessions. The papers will be divided into technical fields on the basis of membership interest in the various fields as measured by a sample in 1952. The following is a preliminary breakdown of the technical program on this basis:

Technical Field	Number Sessions	Number Papers	Percent of Total
Drilling	2	7	14
Geological Engineering	1	3	6
Natural Gas Engineering	1	4	8
Petroleum Economics	1	3	6
Production Engineering:			
Production Equipment	1	4	8
Production Operations	3	9	18
Well Completion	4	12	24
Reservoir Engineering	2	8	16
	15	50	100

The Branch Technology Committee, which is responsible for gathering the papers for the Fall Meetings, was recently reorganized into the six major technical fields shown above. The Committee is headed by a chairman, with a vice-chairman for each of the technical fields.

In addition, the Petroleum Branch Chairman and the Transactions Editorial Committee chairman are members of the Technology Committee ex-officio. The structure of the Committee was designed along these lines to insure that the technical work of the Branch is in proper balance with the technical interests of the membership. William L. Horner, Sunray Oil Corp. in Tulsa, will serve as Chairman of the Technology Committee in 1954, and vice-chairmen for the Committee are now being appointed.

Housing

Downtown hotels in San Antonio have committed 1,350 sleeping rooms for the meeting, and first class motels on the Austin highway have committed an additional 150 rooms. The 1953 meeting in Dallas utilized 1,150 sleeping rooms, and the commitments in San Antonio will be adequate, but more hotels will be utilized. Hotels committing rooms are the Plaza, Gunter, St. Anthony, Robert E. Lee, Menger, Crockett, Blue Bonnett, and White Plaza.

All reservations for sleeping rooms at the meeting will be handled through a housing committee of AIME members. All reservations will be placed with this committee, and the committee will in turn place them on hotels, which will confirm the reservations individually. The entire membership of the Petroleum Branch will be mailed a housing reservation form about February 1, 1954, which can be completed and mailed direct to the housing committee in San Antonio. An effort will be made to give each member a hotel of his choice. The mailing address of the committee will be: Housing Committee, Petroleum Branch, AIME 1954 Fall Meeting, 150 Transit Tower, San Antonio, Texas. However, *you are urged not to send your reservation to this committee until you receive the reservation form by mail.* Any reservations sent direct to a hotel will be forwarded to the Housing Committee, *and will not be filled by the hotel* until placed on it by the committee. The Plaza Hotel will serve as headquarters for the meeting, but it will be able to furnish only about 25 per cent of the total sleeping rooms available. Consequently, the policy has been established that for those companies which request a considerable number of rooms, 25 per cent of the request will be placed on the Plaza (until it is full), and the remainder will be placed in other hotels in the city.

Exhibits and Registration

The lobby, mezzanine, and ballroom of the Plaza Hotel will be utilized for an exhibit and registration area. This will permit the installation of approximately 35 exhibits, a sizeable registration area, and some lounge space.

An advance registration was conducted for the Dallas meeting in 1953, and although only 368 members registered by this method, it was considered very successful. A similar advance registration will be conducted for the 1954 meeting, but it will be refined somewhat and publicized more, and it is anticipated that more members will utilize it this year.

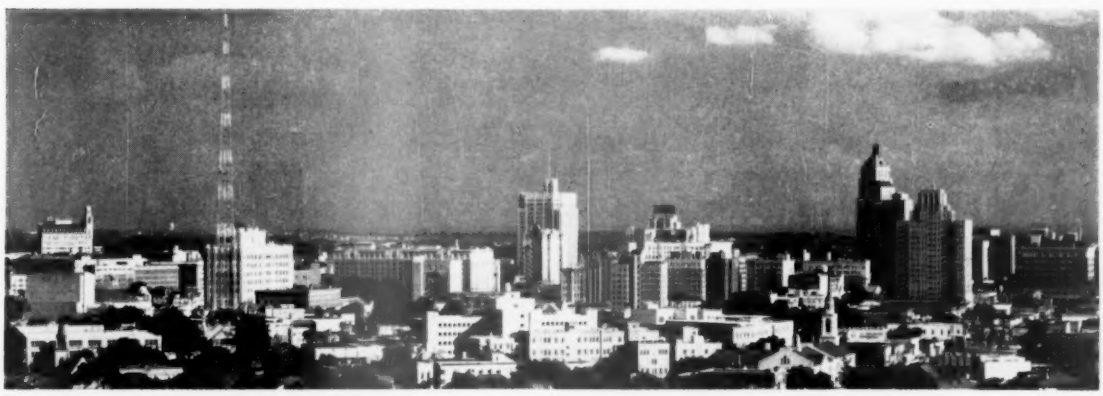
Social Functions

Several social functions that promise to be highly enjoyable are now in the preliminary planning stage. The Welcoming Luncheon will be held on Monday, October 18, in the Roof Garden and adjacent rooms of the Plaza Hotel, which will accommodate an attendance of about 800 persons. This will be for men attending the meeting. A "Frontier Party" is planned for Monday evening, October 19, for men and women. This party will be held at MacArthur Park in North San Antonio, which has spacious facilities for dining and dancing outdoors. Dress for the occasion will be blue jeans, a calico shirt, and other western regalia. The Petroleum Branch Banquet and Dinner Dance will be held in an outdoor setting at Club Sevenoaks on Tuesday evening, October 19. This is a country club on the Austin highway which also has spacious facilities for either indoor or outdoor dining and dancing, along with an excellent kitchen. No restriction will be placed on the attendance for either of these functions, and it is expected that both will be enjoyed by over 2,000 people. Transportation from the downtown area will be provided.

A new feature will be added to the meeting this year, in the form of a Membership Luncheon on Tuesday, October 19, to be attended by members and nonmember male guests. An attractive door prize, such as a set of golf clubs or gun, will be offered. The luncheon will feature a short report on Petroleum Branch activities by the Branch Chairman, followed by an open forum discussion on matters of interest to those attending.

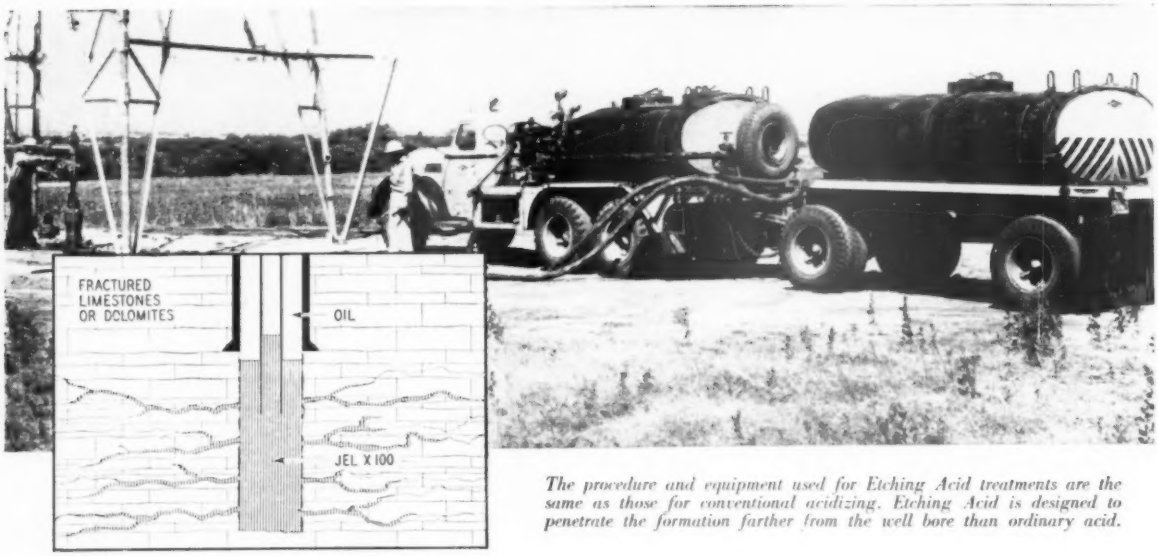
Activities for the ladies only will feature a milk punch breakfast on Monday, October 18, and a luncheon and style show on Tuesday, October 19.

Approximately 2,000 men and 500 women are expected to attend the meeting. ★ ★ ★



ETCHING ACID GAVE RESULTS WHERE REGULAR ACID FAILED

Etching Acid increased production 25 BOPD after ordinary acid treatment failed to boost output



The procedure and equipment used for Etching Acid treatments are the same as those for conventional acidizing. Etching Acid is designed to penetrate the formation farther from the well bore than ordinary acid.

Here's the case history of an oil well that was completed in a limestone formation. It failed to respond to a conventional acidizing treatment, so Dowell was called in for consultation on the job. Dowell engineers analyzed the well and recommended an Etching Acid treatment. This suggestion was followed and production was increased from 8 to 33 BOPD.

Etching Acid treatments, using Jel X 100, are primarily suited for use in limestone or dolomitic formations with either fractured or vugular porosity. Etching Acid is designed to etch fractures or "vugs" . . . to clean fractures by removing calcite, mud, silicate and feldspar materials . . . to penetrate formations far from the well bore before the acid becomes spent. No auxiliary jel-breaker solution is required following Etching Acid.

If you would like to know more about Etching Acid or any of the many other Dowell oil field services, contact the nearest Dowell office. Or, if you prefer, write directly to Tulsa, Dept. A-15.

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The Value of a Barrel of Crude Oil

OUTLINE

GROSS INCOME PER BARREL OF OIL, MARKET PRICE	$2.75
VALUE OF GAS AND GASOLINE PRODUCED WITH ONE BBL. OF OIL	.25
TOTAL GROSS INCOME PER BARREL	$3.00
COSTS :—	
ROYALTY (BASIC & OVERRIDES) @ 1/6	.50
DEPLETION, LAND COSTS INCLUDING GEOLOGICAL & GEOPHYSICAL CAPITAL	.10
DEPRECIATION, DRILLING COSTS AND LEASE FACILITIES	.35
PRODUCTION, LIFTING	.40
MANUFACTURING, GASO. ABSORPTION	.05
TAXES, AD VALOREM (COUNTY TAXES)	.15
GENERAL EXPENSE DEPTMTAL MANAGEMENT, ETC.	.05
TOTAL COSTS	$1.60
OPERATING INCOME (PROFIT)	1.40
PRESENT WORTH PER BARREL @ .7	$0.98

The starting point in this valuation is the market price or posted price of the barrel of crude oil, for the value dealt with in this article is that which the producer gets by selling the crude at the well.

The figures in the accompanying table are for illustrative purposes only. Although they do not apply to a particular crude, they are in proper proportion. In this hypothetical case slightly more than 50 per cent of the income has been consumed in accounting the costs of producing a barrel of oil. This is not an unusual case, though costs do vary over a wide range, and just as much care should be taken in estimating costs as in estimating oil reserves.

EXPLAINING THE TABLE

The gross income per barrel of crude is the posted price of crude oil in the field. It varies much more with the gravity in California than in areas east of California, as shown in Fig. 1. In many of the eastern fields one price prevails, since the variation in gravity is only two or three degrees. In 1953 in California the difference between the high and low posted prices of crude was $2.20, indicating a depressed condition for the heavier type crude.

The value of gas and gasoline associated with a barrel of crude oil depends upon: (1) gas-oil ratio, (2) gasoline content, and (3) location of field in relation to facilities and markets for gas. Natural gasoline prices have increased 76 per cent in the last 14 years. On the average, natural gas prices have increased a like amount.

Costs Involved

Royalty can be considered as a cost rather than a purchase of crude, since in most cases royalty oil is paid for in cash. In general, royalty rates vary from 1/8 to as high as 60 per cent. In California royalties are generally from 1/8 to 1/4.

By

W. S. Eggleston
Union Oil Co. of California
Member AIME

As Reported by

C. R. McEwen
Pacific Technology Forum
Junior Member AIME

Land costs include that certain amount customarily set up as chargeable to the purchase of mineral interests, as distinguished from wells and facilities. This is simply one of the costs of doing business. Usually the cost of land and capitalized geophysical and geological expense is charged off against each barrel of oil produced. For instance, if the land costs $75 per acre, and capitalized geological and geophysical work $25 per acre, the total of $100 would be divided by the estimate of reserves — say 10,000 bbls per acre. Depletion could then be one cent per barrel. A survey covering the United States a few years ago yielded an average value of six cents per barrel. Note that this item has nothing to do with the cost of finding oil, nor should it be confused with statutory depletion, which is an allowance by the Department of Internal Revenue to take care of the exhaustion of a capital asset.

Depreciation rate is the total cost of drilling, including a portion of the lease facilities, divided by the reserves. In the last 11 years the cost of drilling has increased about 48 per cent. In general, the depreciation cost to be charged against a barrel of oil ranges from 20 cents to 80 cents, although the cost can be both above or below these figures.

Lifting costs or *production costs* include all of the field costs of producing oil, such as labor, supplies, transportation, fuel, cleaning and waste water disposal, maintenance, and supervision in the field. After the flowing life of the well is past, the cost will generally climb steadily from eight or nine cents to perhaps more than 60 cents per barrel. An average cost for the life of a well will often be in the

(Continued on Page 60)

CRUDE OIL PRICES AS OF AUGUST 1, 1953

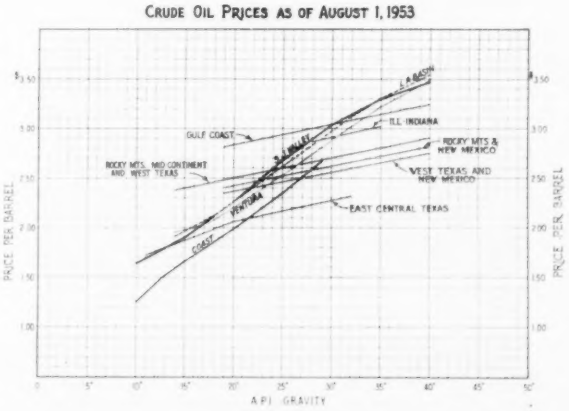

FIG. 1

advantages of BAKER Stage Cementing

You can save casing by Stage Cementing the Baker way, because with *only* one string of casing you can cement off at the shoe *and* shut off surface water. Or you can cement a well with *two producing zones* and be assured of uncontaminated cement for the upper zone. And you *never* need risk breaking down a comparatively weak formation by high cementing pressure and the extreme weight of a long cement column.

BAKER STAGE CEMENTING COLLAR

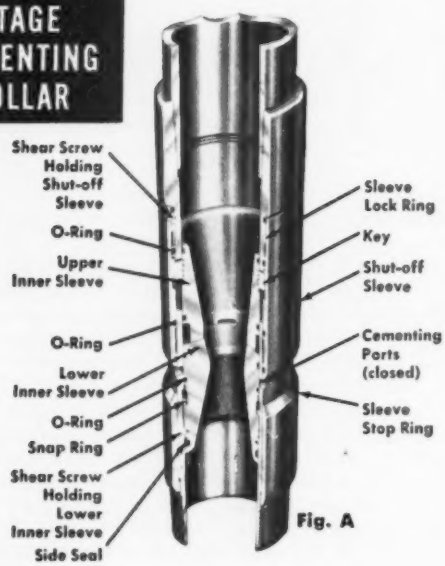

Fig. A

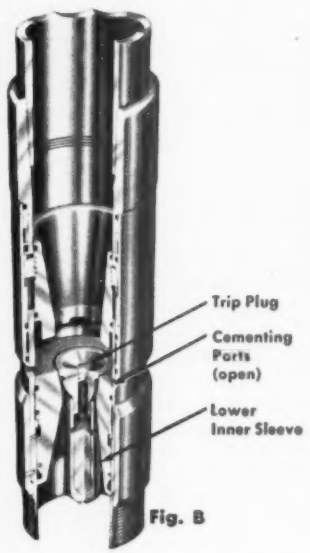

Fig. B

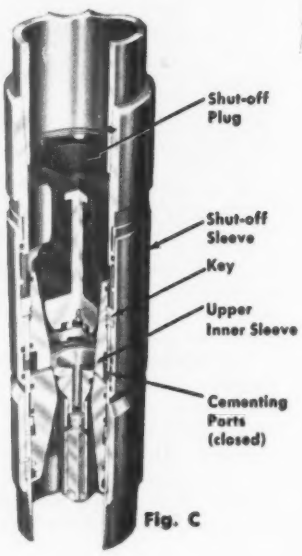

Fig. C

Fig. A—Ready for cementing the first stage. The cementing ports are covered by the Lower Inner Sleeve which is held in position by shear screws; shear screws also hold the Shut-Off Sleeve above the cementing ports. The Baker Flexible Cementing Plug (shown on opposite page) will pass through the Stage Collar without shearing the screws holding the Inner Sleeves.

Fig. B—Ready for cementing the second stage. After the Trip Plug is seated, application of hydraulic pressure shears the screws holding the Lower Inner Sleeve which moves downward, thus uncovering the cementing ports. The Trip Plug prevents passage of fluid into the casing below, and cement pumped into the casing will now pass through the cementing ports for the second-stage cementation.

Fig. C—Second-stage cementation is completed. The Shut-Off Plug has been pumped down the casing and pressure applied to shear the screws and move the Shut-Off Sleeve downward to close off the cementing ports. Note how the Sleeve Lock Ring has expanded to lock the Shut-Off Sleeve in position permanently covering the cementing ports.

See opposite page for details of operation.

IT'S SIMPLE, SPEEDY AND SAFE to perform two-stage cement jobs with Baker Stage Cementing Collars (Product No. 200-F) in combination with other Baker Equipment. In addition to positive, mechanical closing of the cementing ports upon completion of the second stage, you are assured of these outstanding advantages:

1 After the second stage has been completed, an external steel sleeve with an oil-resistant synthetic rubber seal provides positive closure and prevents passage of fluid between the inside and the outside of the casing, regardless of the condition of the cement job at that point.

2 The cementing ports of the Stage Cementing Collar may be opened at any time after completion of the first stage, and fluid may be circulated through the stage collar for any desired length of time before starting second-stage cementing.

3 Operation of the stage collar is effected by fluid pressure applications only, and no movement of the casing is required after the first stage of the cementation has been completed.

4 All internal parts of the Baker Stage Cementing Collar are constructed of readily drillable materials, and when drilled out there are no sharp shoulders or irregularities to interfere with the subsequent passage of tools through the collar.

5 Since the steel Shut-off Sleeve is on the outside of the Stage Cementing Collar, there is no possibility of accidentally opening the cementing ports when drilling out the internal mechanism, or later when bits or casing scrapers are run through the collar.

Here's how a typical **two-stage** cementing job is performed with the **Baker** Stage Cementing Collar

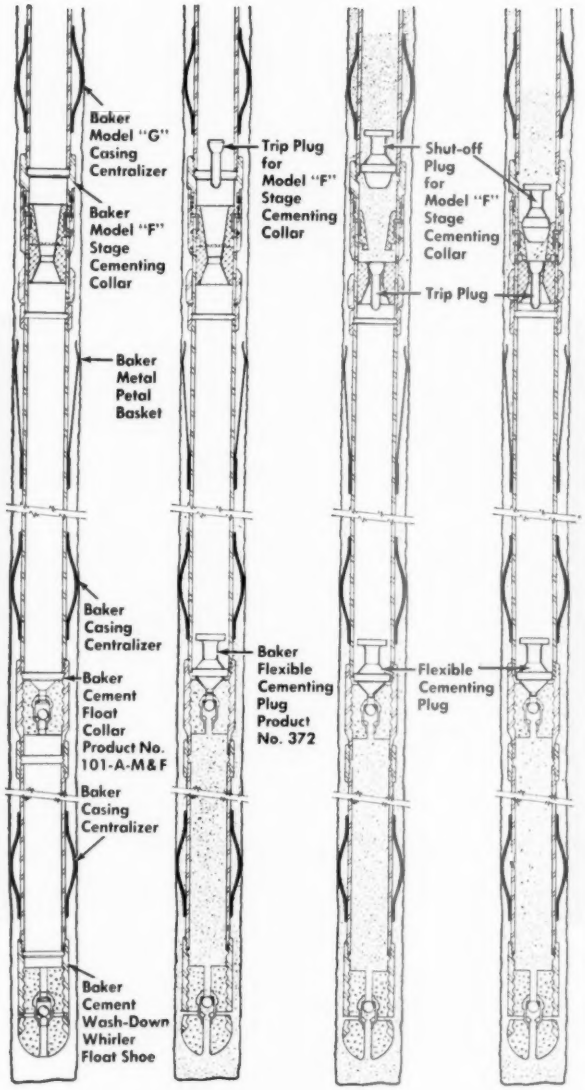
Baker Model "G" Casing Centralizer
Baker Model "F" Stage Cementing Collar
Baker Metal Petal Basket
Baker Casing Centralizer
Baker Cement Float Collar Product No. 101-A-M&F
Baker Casing Centralizer
Baker Cement Wash-Down Whirler Float Shoe
Trip Plug for Model "F" Stage Cementing Collar
Baker Flexible Cementing Plug Product No. 372
Shut-off Plug for Model "F" Stage Cementing Collar
Trip Plug
Flexible Cementing Plug

Figure 1 Figure 2 Figure 3 Figure 4

Ask any Baker representative or office for recommendations to make your stage cementing operations successful, "first-time" accomplishments.

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Fig. 1—Hook-Up in Running-In and Mud-Conditioning Position. The string (starting at bottom) consists of a Baker Cement Wash-Down Whirler Float Shoe for conditioning the hole, washing away bridges, and cementation of the lower (first) stage. Baker Casing Centralizers are positioned at strategic points (as illustrated) to center the casing, ensure annular clearance, and avoid channeling of the cement slurry. Next above is a Baker Cement Float Collar with Seat for Flexible Plug, Product No. 101-A M.& F. A Baker Metal Petal Basket (optional equipment) is positioned just below the Stage Cementing Collar to retain all cement slurry *above* the Basket when the second-stage cementation is performed. Note that Baker Casing Centralizers are used just above the Stage Cementing Collar to ensure annular clearance for the upward movement of the cement slurry.

Fig. 2—The first-stage cement job has been completed. The Flexible Plug has been pumped through the Stage Collar to its seat in the bevelled top of the Float Collar where it prevents over-pumping and also separates the cement slurry from the follow-up fluid. The Trip Plug has been placed in the casing and is gravitating to its seat in the Lower Inner Sleeve of the Stage Collar; see also Fig. B on opposite page. Application of hydraulic pressure, after the Trip Plug is seated, will result in opening of the cementing ports.

Fig. 3—The second-stage cement job is almost completed. The cement slurry has passed through the open ports, and the Shut-Off Plug (acting as a separator) is approaching its seat in the Upper Inner Sleeve of the Stage Collar. Note how the Baker Metal Petal Basket has prevented downward movement of the cement.

Fig. 4—Both stages have now been successfully cemented. The cementing ports are closed off by the Shut-Off Sleeve which is locked in position as shown in Fig. C on opposite page. When the cement has set, the readily drillable internal mechanism of the Baker Stage Cementing Collar, Float Collar and Float Shoe are removed by the drilling bit leaving the full I.D. of the casing free from any sharp shoulders or other obstructions, ready for all subsequent operations.

USE BAKER STAGE CEMENTING COLLARS

February 13-17

New York Meeting Features Full Program

The presentation of nine technical papers, the Annual Production Review Session, and the open meeting of the Petroleum Branch Executive Committee are Petroleum Branch highlights at the 1954 Annual AIME Meeting in New York.

General AIME meetings and social events will fill out the packed schedule at the Feb. 13 to 17 event in the Statler Hotel. Morris Muskat is the general chairman of Petroleum Branch activities.

The Council of Section Delegates meeting at 10 a.m. Saturday, Feb. 13, will begin the activities. The AIME Board of Directors will meet at 2 p.m. Sunday, Feb. 14. Registration starts Monday, Feb. 15, at 8 a.m.

The open meeting of the Petroleum Branch Executive Committee will be held at the Keystone Room, Hotel Statler, at 9 a.m. Monday. At 12:15 p.m. the AIME Welcoming Luncheon is scheduled. Dr. Grayson Kirk, President of Columbia University, will be the speaker.

R. B. Gilmore of DeGolyer and MacNaughton, Dallas, will preside over the Annual Production Review Session scheduled for 2 until 5 p.m. Monday. Highlights of world-wide oil and gas developments and production during 1953 will be given. The AIME Stag Smoker, featuring the floor show from the Latin Quarter, at 7:30 p.m., rounds out the day.

Technical sessions will be the feature Tuesday and Wednesday. At 6 p.m. Tuesday the Petroleum Branch Cocktail Party and Dinner will take place at the Keystone Room. A speech by Frank M. Porter, President of API, and installation of Petroleum Branch officers for 1954 are scheduled. The AIME Annual Banquet and President's Reception will be at 7 p.m. at the Ballroom of the Statler and is the final event of the meeting. Abstracts of papers to be presented are given below:

TUESDAY, FEB. 6

The technical session is to last from 9 a.m. to 12 m. Kenneth E. Anderson and Raymond E. Howard will serve as associate chairmen.

346-G

Analysis of Flooding Horizontally Fractured Thin Reservoirs

Paul B. Crawford, R. E. Collins | Texas Petroleum Research Committee, College Station, Texas

A study has been made of the effect of circular horizontal fractures on the flooding characteristics of the five spot, line drive and seven spot patterns. The study was restricted to thin reservoirs. For 660 ft well spacing it is shown that circular fractures of near 20 to 30 ft radius may increase the conductivity of the pattern from 50 to 300 per cent, depending on whether one or all wells are fractured and the type of flooding pattern used. For the conditions studied 20 to 30 ft fractures may serve to decrease the sweep efficiency by about 1 per cent. Long fractures up to 150 ft radius may result in a decrease in floodout time by factors of three to 10. The advantages of fracturing existing water input wells and postponing fracturing until the oil-water interface is beyond the possible fracture radius are discussed.

347-G

A Magnetic Susceptibility Method for the Determination of Fluid Saturation in Porous Materials

J. W. Whalen | Magnolia Research Co. Laboratories, Dallas, Texas

The design and operation of an instrument for the external determination of fluid saturation in porous materials is described. In the use of this instrument the magnetic susceptibility of a core sample and its interstitial fluids is determined from a mutual inductance measurement. A high magnetic susceptibility is imparted to the aqueous phase through the use of cobaltous chloride as a tracer.

The response characteristics of the instrument are compared with those of other techniques currently in use and the advantages of the magnetic susceptibility method are discussed. Two liquid phase relative permeability data, illustrative of the use of the technique, are shown.

349-G

Use of Radioactive Iodine as a Tracer in Water-Flooding Operations

J. Wade Watkins | U. S. Bureau of Mines, Bartlesville, Oklahoma
E. S. Mardock | Well Surveys, Inc., Tulsa, Oklahoma

The complete evaluation of reservoir-performance characteristics in the secondary recovery of petroleum by water-flooding requires the use of a water tracer that may be injected into water-input wells and detected at oil-production wells for the purpose of supplementing and correlating the data obtained from core analyses, wellhead tests, and subsurface measurements. Radioactive iodine has been used successfully as a water tracer in field tests to determine: (1) Relative rates and patterns of flow of injected water between water-input and oil-production wells and (2) vertical zones of excessive water entry into oil-production wells.

Preliminary laboratory evaluations of potential water tracers, the use of core-analysis, wellhead-test, and subsurface-measurement data in selecting locations suitable for tracer tests, and surface and subsurface instruments used for detection of the emitted gamma radiation, are summarized. Data from field tests are presented graphically and discussed in detail.

It is concluded that radioactive iodine is advantageous as a tracer for both purposes under conditions of comparatively rapid transit time between wells.

AFTERNOON SESSION

The session scheduled from 2 until 5 p.m. is concerned with "Economic, Geological, and Political Factors of World Oil Prospects." Douglas S. Ball and Ray Elner are the associate chairmen.

351-G

WORLD OIL PROSPECTS — FROM A GEOLOGICAL VIEWPOINT

Hollis D. Hedberg | Gulf Oil Corporation, Oakmont, Pennsylvania

Both world oil production and world oil reserve increase persistently year after year. These increases come mainly not from new oil-producing regions but from further development of long-established regions constituting only a small fraction of the world's prospective oil territory. Many of the remaining regions have not yet been adequately reconnoitered, so odds still strongly favor additional highly productive discoveries. However, already-indicated variations in oil endowment suggest also that many regions will always remain barren or poorly productive even though apparently possessing all superficial requisites. Mere sedimentary volume is no index of oil potentiality. Moreover even presence of adequate source, reservoir, cover, and traps may be nulified by the factor of timing.

352-G

POLITICO—ECONOMICS OF THE WORLD'S OIL INDUSTRY

H. J. Struth | World Petroleum Statistical Yearbook, Dallas, Texas

Factual evidence draws a sharp line of contra-distinction between nations which impose government monopoly upon industry, and those that offer encouragement to private capital and freedom of enterprise.

The effects of nationalization of petroleum in 19 political sub-divisions of the world prove conclusively that discovery and development have been retarded; that revenues are far less lucrative than those returned by private capital; that economic progress and public welfare are retrogressive.

Nations operating under a system of free enterprise are far more progressive; thier people enjoy higher living standards. In 23 countries, where government monopolies are non-existent, oil reserves comprise 78 per cent of the world total; production accounts for 88 per cent. Of the combined passenger automobiles registered by all oil resource nations, the citizens of the free-enterprise group own 96 per cent.

353-G

ECONOMIC ASPECTS OF WORLD PETROLEUM SUPPLY AND DEMAND

Serge B. Jurenev | Continental Oil Co., New York, New York

During the past quarter of a century, world crude oil production (outside of Iron Curtain countries) increased roughly 3½ times. This increase was unevenly distributed, with United States production increasing 2.4 times and elsewhere in the world, more than sixfold.

The increase in United States production has generally followed the expansion in demand. Forecasts as to the magnitude of future growth in demand for petroleum and its products seem to agree that the annual rate of production will be below that experienced in the past.

Current production abroad exceeds foreign requirements, and potentialities of future discoveries also seem greater outside of the more thoroughly-explored United States. Therefore, the conclusion is unavoidable that crude from sources other than the United States will affect the world oil markets to an ever increasing extent. It also follows that the United States domestic markets for crude oil will be affected by foreign developments to a much greater degree than heretofore.

WEDNESDAY, FEB. 17

The technical session is scheduled from 9:30 a.m. until 12 m. R. K. MacIvor and H. E. Treichler, Jr., are associate chairmen.

293-G

LIQUID FUELS FROM OIL SHALE

A. C. Rubel | Union Oil Co. of California, Los Angeles, California

Shale deposits of northwestern Colorado contain more than 100 billion barrels of recoverable shale oil from which, by processes now developed, high quality liquid fuels, gas, sulfur, ammonia and petrochemical products may be produced.

Experience during the past two years indicates that in the immediate future we face an increasing dependence upon crude supplies outside of the United States.

Studies conducted by the National Petroleum Council indicate that a considerable proportion of this shale oil may be recovered and processed into products equal to those from natural crudes on the Pacific Coast at a cost closely approaching current prices from natural crudes.

It would therefore seem to be in the public interest for the petroleum industry and the Defense Department to thoroughly explore the possibilities of developing this great resource as a supplement to our domestic crude supply.

Immediate industry study on an expanded pilot plant scale is suggested.

312-G

A TEN-POUND CEMENT SLURRY FOR OIL WELLS

Roscoe C. Clark, Jr. | Continental Oil Company, Ponca City, Oklahoma

In many oil producing areas considerable difficulty is encountered in casing cementing operations in obtaining a satisfactory "fill-up." It is generally accepted that the reason for this difficulty is that the cement slurries in use are of sufficiently high density and that zones of lost circulation are created into which the cement is lost. Bentonite and expanded perlite are currently in use as additives to cement slurries for the purpose of decreasing slurry weights. These additives have been effective in many cases; however, in other cases cement "fill-ups" are still difficult to obtain, and in others cement strength development has been seriously impaired by the addition of too much bentonite or expanded perlite. At present cement weights cannot be decreased below 12 pounds per gallon (under bottom hole conditions) without loss in desired strength. A new additive has been developed which can be used to safely reduce cement slurry weights to as low as 10 pounds per gallon.

(Continued on Page 60)

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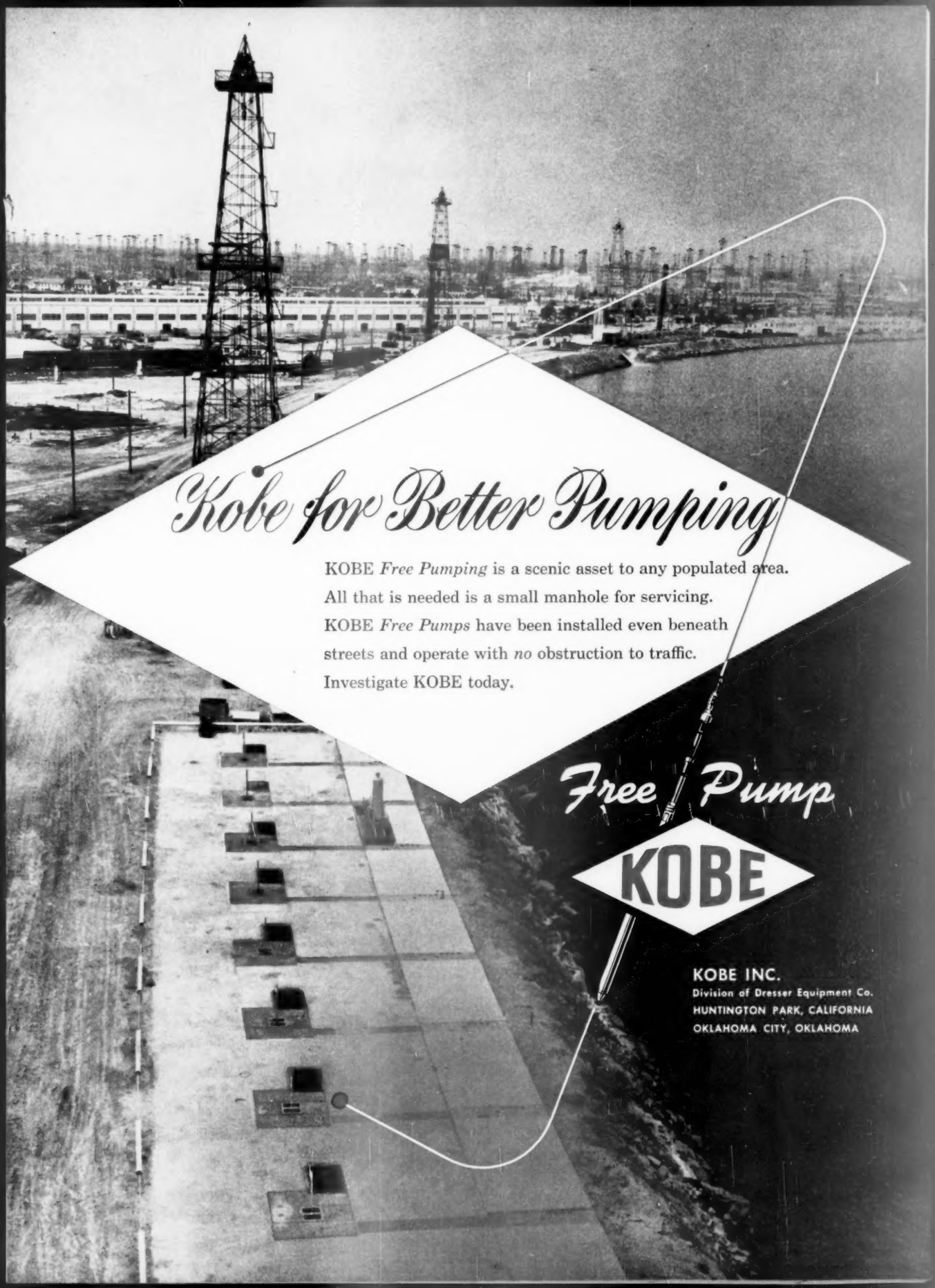
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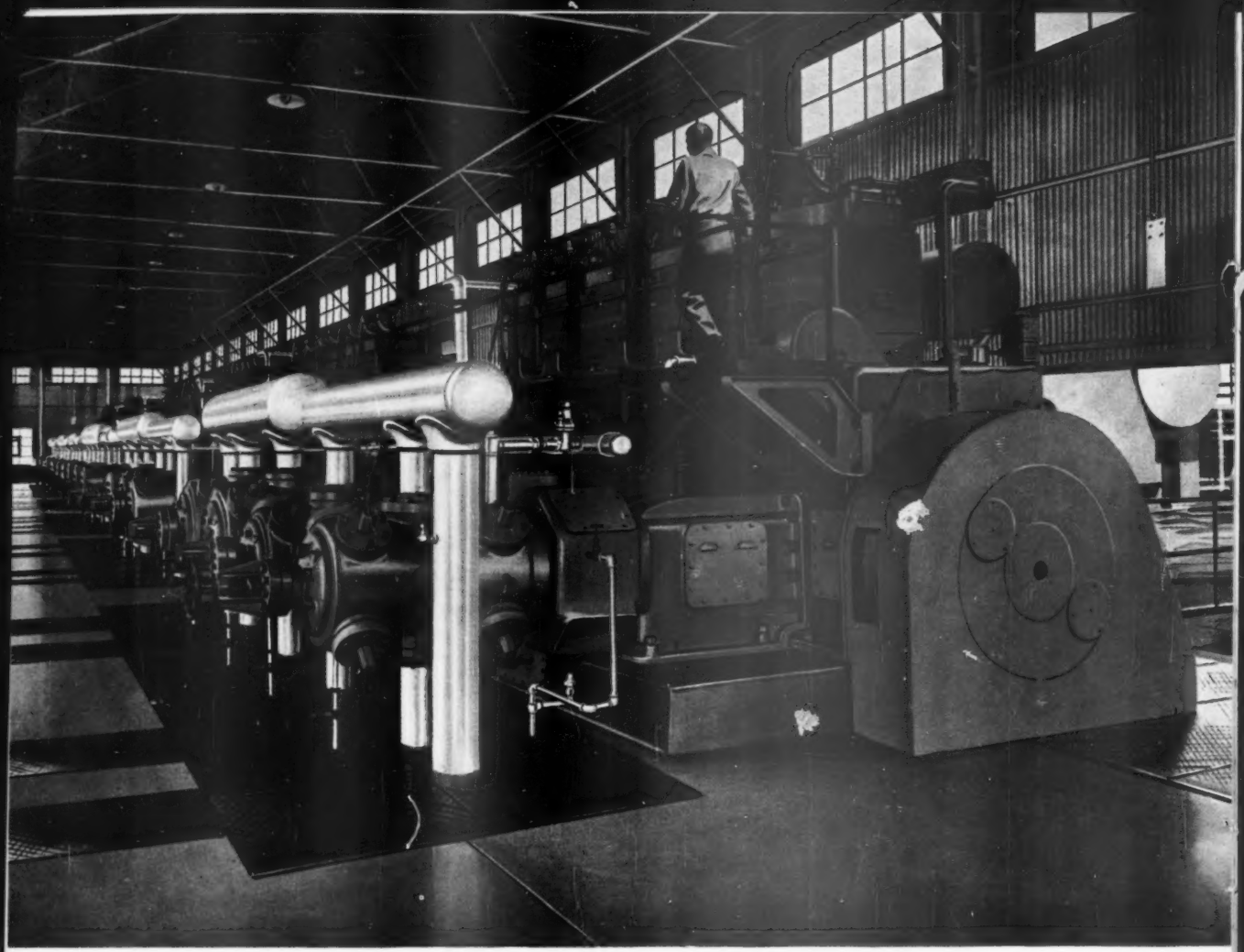

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KOBE, INC., DIVISION, Huntington Park, Calif. Complete hydraulic oil field pumping systems, including the Kobe Free Pump.

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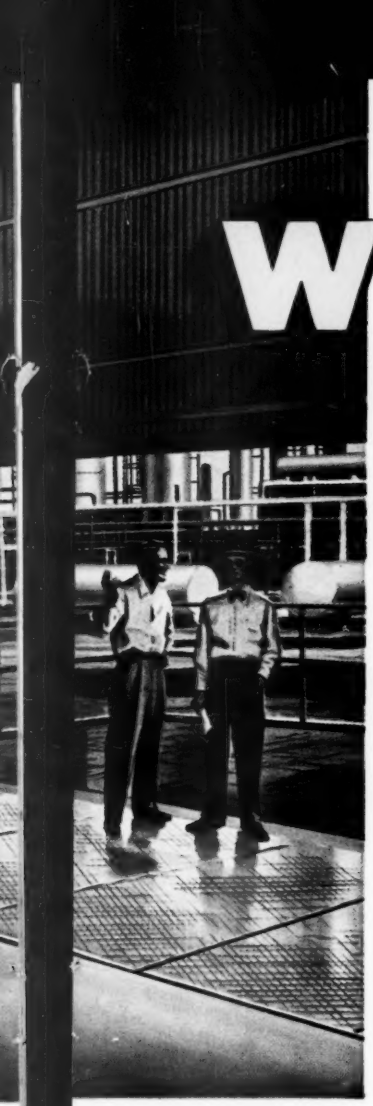

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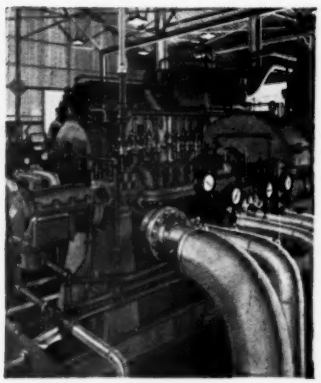

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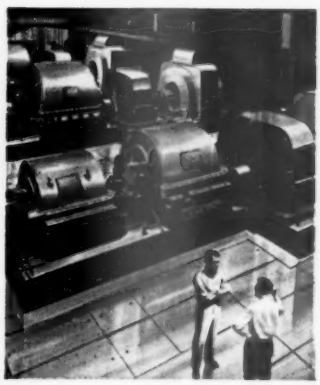

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SECURITY ENGINEERING DIVISION, Whittier, Calif., Dallas, Tex. Rock bits, reamers, casing scrapers, reamer rock bits, coring bits, Securaloy.

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An Evaluation of the Functioning
Of Automatic-Controls Equipment Tested Under
Conditions Simulating Coastal and Offshore Operations

Automatic Lease Operations — Weeks Island Field, La.

Turner P. Northern

Gulf Refining Company

INTRODUCTION

The upward trend of oil production, which usually amplifies producing problems, combined with a search for improved economic and efficient methods have revealed the possibilities of automatic producing facilities along the Gulf Coast.

In 1952 the Gulf Coast District of the Gulf Refining Company's Houston Production Division initiated a plan for testing and appraising various types of automatic lease equipment for use in bay fields and offshore operations. Under this plan a small lease was selected, where operating and flowing conditions are similar to coastal and offshore wells. By such a method the performance of all equipment could be observed and evaluated prior to more complex situations.

Gulf's Provost Cyr Unit lease was selected for the installation. It consists of 158.70 acres and is located on the east flank of the Weeks Island field, in Iberia Parish, La. The first well was completed in March, 1950. When the drilling program terminated in January, 1953, production had been established from five wells. The calendar daily allowable for the month of June, 1953 was 1,254 bbls. All wells are produced by natural flow through positive chokes at the well-head. Flowing tubing pressures range from 800 psi to 1,800 psi. Two of the wells are producing salt water. API gravity of the crude ranges from 30.9° to 35.0°.

Producing equipment on this lease consists of four 1,000 bbl stock tanks, one 500 psi oil and gas separator, two 125 psi oil and gas separators, one emulsion-type heater-treater, and one horizontal precipitator. All are connected with adequate manifolds and piping to serve their specific purpose in production of oil and gas.

Electricity is available at the lease from a utility company.

REQUIREMENTS OF EQUIPMENT

Basic requirements must be met in order to completely produce a lease automatically. First, some type of tank switcher is necessary which will transfer flow from one tank to another when a predetermined fluid level (full) is reached. The set-up must insure that flow cannot be transferred to tanks either full or on pipeline run.

Control must be maintained over the opening and closing of the wells. Wells must be closed in when: (1) no tank space is available, (2) a well is produced on a pre-determined schedule, or (3) a failure occurs in the producing equipment. This should be an automatic operation, accomplished by closing in the well preferably near the well-head. In the event of a pumping well, the prime mover must be stopped.

SELECTION OF EQUIPMENT

Tank Switching Equipment

Principal components of the tank switching equipment selected for the installation consisted of a tank switching panel, tank inlet valves, tank float switches, and pipeline valve switches.

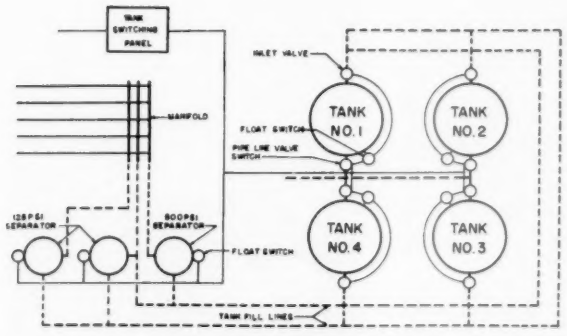

FIG. 1 — DIAGRAM SHOWING GENERAL LOCATION OF TANK SWITCHING EQUIPMENT.

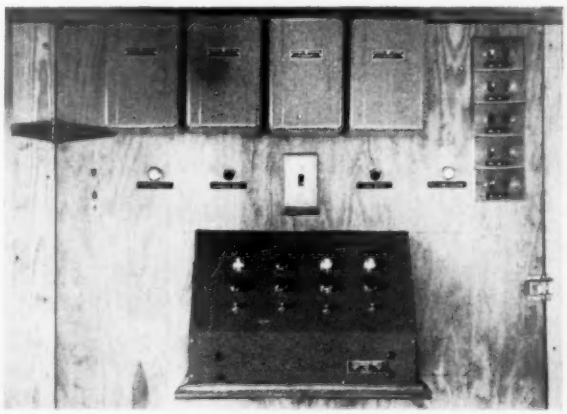

FIG. 2 — TANK SWITCHING PANEL — FRONT VIEW.

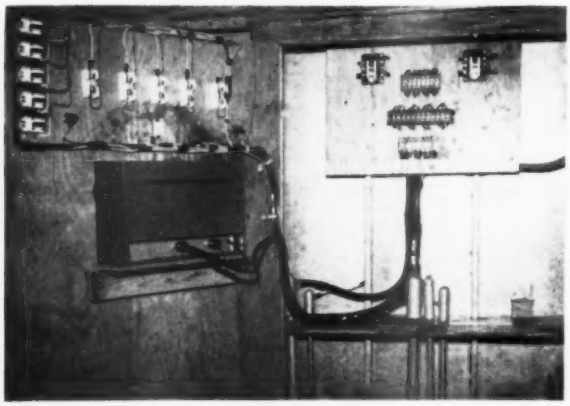

FIG. 3 — TANK SWITCHING PANEL — REAR VIEW.

FIG. 4 — METAL BUILDING USED TO HOUSE TANK SWITCHING PANEL.

All of these items are electrically operated and require electrical energy from an outside source. They are connected by electrical wiring and each tank's installations function as a unit.

1. Tank Switching Panel. The tank switching panel is the nerve center of the automatic operations. Every other component of the system is dependent on it in some manner. The panel selected was an electrical device that selects tanks in numerical sequence. Those either full or on pipeline run are bypassed and the production transferred to the next available tank. In the event that no stock tank is available for receiving the oil, all wells are closed-in simultaneously by the tank switching panel.

Each tank operating from the switcher has its associated hydraulic valve control relay and indicating lights. These indicate the condition of that particular tank, i.e., empty, filling, or full. The relays are directly operated from a selector disc by electrical contact of cylindrical carbon brushes, mounted above the disc with a copper contacting strip inlaid in the selector disc which is made of a non-conductive plastic.

2. Tank Inlet Valve. The valve selected for this position in the system was an electrically-operated, explosion proof, hydraulic valve, which was installed in the fill line of each tank. Normally the closed type is used. This type is opened when energized electrically and closes when de-energized, meaning it will always close in the event of a power failure. The valve is fully ported to handle quantities of fluid, and requires 115-volt, 60-cycle electrical energy for operation.

3. Tank Float Switches. A side-mounted, explosion-proof float switch was chosen for this assignment. It is simple in installation and operation. The float is connected to a mercury switch which breaks electrical contact on high level. The mercury switch is wired in series with the pipeline switch and the tank filling valve control relay. Thus, a break of electrical contact by the switch upon the tank becoming

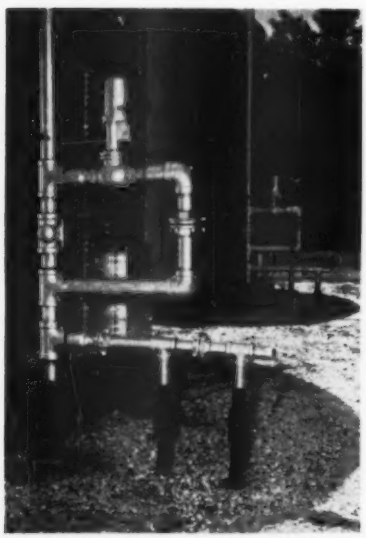

FIG. 5 — TANK INLET VALVE.

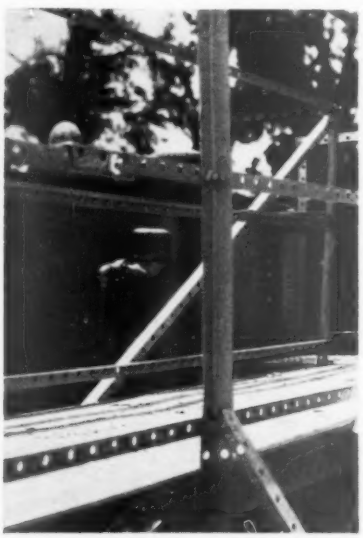

FIG. 6 — TANK FLOAT SWITCH.

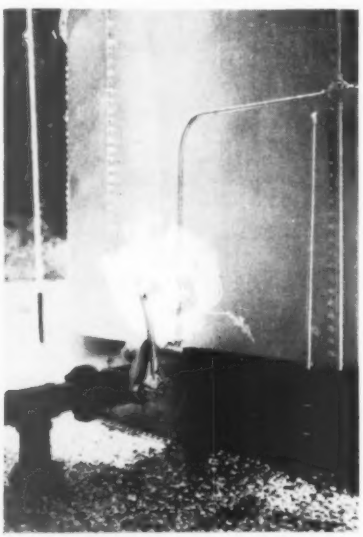

FIG. 7 — PIPELINE VALVE SWITCH.

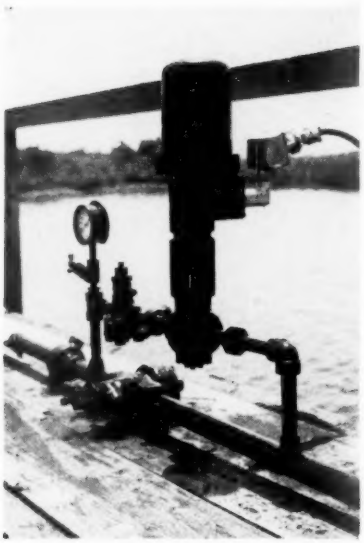

FIG. 8 — WELL HEAD VALVE — ELECTRICALLY DRIVEN HYDRAULIC TYPE.

full causes the inlet-valve control relay to de-energize the valve and preventing further flow into that particular tank. Upon opening the pipeline valve for a pipeline run, the pipeline switch also opens this circuit, which prevents the tank filling valve from becoming energized when the fluid level in the tank is lowered and the float switch again makes contact. Such a hookup requires a minimum of wiring around the stock tank.

4. Pipeline Valve Switches. Pipeline valves on all stock tanks were of the wrench-operated-plug type; thus, no valve replacements were required. Under such conditions it was necessary only to remove the lock-stop ring on the valve and replace it with a valve-switch assembly. The assembly consists of an explosion-proof mercury switch which breaks contact upon the opening of the valve. Before this switch functions properly it must be mounted in a plane that makes or breaks contact upon opening and closing of the valve.

WELL FLOW CONTROLS

Under operating conditions on the Provost Cyr Unit lease, all wells produce 24 hours per day. The well-flow control requirements are to close-in wells when no storage space is available, or when there is a failure in automatic lease operations.

Two types of control valves were used in controlling the flow of the five wells. On four or the five wells, electrically-operated, explosion-proof, hydraulic valves were installed. This is a 1 in. fully-ported, normally-closed valve, 2000 psi working pressure, 115 volts, 60 cycle. It was installed in a bypass near the well-head and is connected to the tank switching panel by an electric line.

The flow control on one well consists of two valves, one located at the well-head, the other in the flowline near the well manifold which is in the vicinity of the tank battery.

The valve located near the well manifold is a normally-closed, pressure-operated, mechanical valve actuated by a solenoid. The solenoid must be energized by electrical energy before the valve opens. The valve on the well-head is a pressure-operated mechanical valve. It is controlled by a bourdon-tube-type pilot with low shut-off attachment, the flowline pressure serving as the controlled medium. Supply gas for the pilot is obtained from a fabricated drip located downstream from the valve.

The control on the well with the mechanical valve does not require any electric connections at the well. It was installed to obtain information concerning control without electric lines to the well-head since such lines are unpractical in bay fields and offshore operations.

SEPARATOR FLOAT SWITCHES

As a precautionary measure against mechanical failures which might flood the system with oil, safety shut-down float switches were installed on all oil and gas separators.

On the two 125 psi separators, the inside type float switch was used. It is installed on the side of the vessel with regular pipe thread connections. This float switch operates from an explosion-proof mercury switch which will either make or break contact on liquid level rise.

The float on the 500 psi separator is an externally-mounted pick-up type float with an explosion-proof mercury switch which makes contact on liquid level rise. All float switches are wired in parallel and are connected to the tank switching panel.

FLOW OPERATIONS

Electrical energy for automatic lease operations is furnished at the tank battery by an outside source. From a power-line pole located an adequate distance from the producing equipment, the power is transmitted into the 8 ft x 8 ft x 7 ft prefabricated metal house. This building, which is located outside the tank battery firewall, houses the automatic tank switching panel. It is the control point of the entire system. As a safety measure all electric lines passing to and from the panel were installed underground in galvanized conduit. As a further safety precaution and to prevent malfunctioning of the control system from grounds on the associated 110-volt line, an insulating transformer was installed in the incoming line.

From inside the metal house the functioning of the entire system can be observed. In addition to the tank switching panel, other controls include a full-separator indicator, full-tank indicator, time-relay well controls, and individual well switches.

On the tank switching panel, storage space in a stock tank is indicated by a lighted green light. Whenever a tank is filled, the corresponding green light on the panel will go out and flow will be transferred to the next empty tank. No green light for a tank will burn as long as the tank's pipe line valve is open. This eliminates the problem of producing into a tank while it is on pipe line run. The tank being filled is noted by a red light on the panel and only one tank can be filled automatically at one time.

When all of the stock tanks are full, or are being run by pipe line, the wells are closed in. This is shown by two signals, which are: a full tank light on

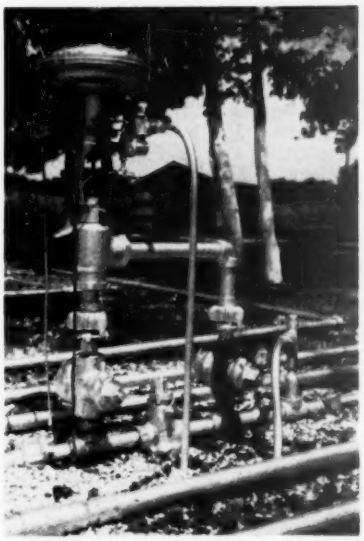

FIG. 9 — FLOWLINE VALVE — PRESSURE OPERATED MECHANICAL VALVE WITH SOLENOID.

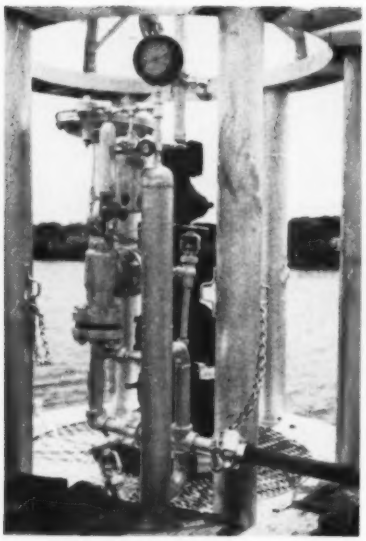

FIG. 10 — WELL HEAD VALVE — PRESSURE OPERATED MECHANICAL TYPE.

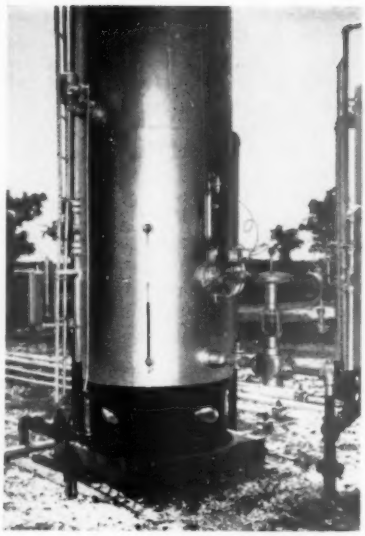

FIG. 11 — SEPARATOR FLOAT SWITCH — PICKUP TYPE.

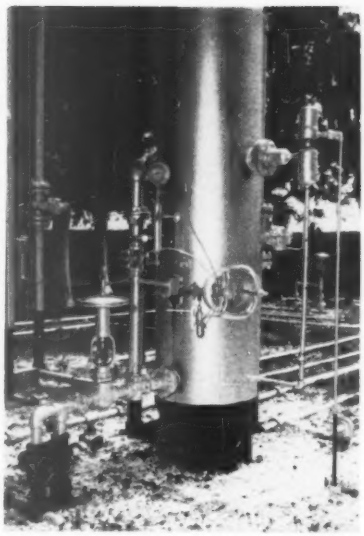

FIG. 12 — SEPARATOR FOAT SWITCH — INSIDE TYPE.

the control panel and a corresponding light burning on a pole near the separators, which may be seen from convenient points around the lease. A tank reset button must be pushed when space is available before the lease again resumes operation.

If for any reason one of the oil and gas separators fails to function properly and fills with fluid to a pre-determined level, an automatic float switch is tripped and the wells are closed in. A signal of this will be indicated by signal lights burning on the control panel and on a pole near the tanks. Should the field close in for this reason, it will remain closed in until the separator reset button on the control panel is pushed, resuming automatic operations. This hookup makes it impossible for the wells to start producing after some mechanical failure until company personnel have had an opportunity to inspect and make corrections. When the wells are shut in due to high fluid level in a separator, the tank inlet valve on the tank being filled will remain open. This allows for fluid expansion in the flow lines and tank filling lines.

Due to reservoir conditions, these wells flow heads of gas for several minutes when opened for production after being shut in for long periods. In order to control this flow of gas, time relay switches regulate the opening of the well-head valves at controlled intervals. By such a method no producing equipment can be overloaded with gas for a short period, which might result in a relief valve opening and popping the gas to atmosphere.

Individual well switches are located on the control panel. At this control panel any well may be taken from automatic operations by only pulling a switch. If flowing of a well without this control is desired, a bypass valve near the well-head must be opened.

Individual tank switches are also located on the control panel, permitting any tank to be removed from the automatic control. A bypass around the tank inlet valve can be opened for manual operations. Such bypasses are used for manual operations during monthly testing of all wells which is required by the Louisiana Department of Conservation.

CONCLUSIONS

Automatic tank switching and well flow control can be successfully carried out under conditions similar to those in bay fields and offshore operations.

Corrosion, transportation, and shortage of installation space are examples of the many problems which can be best solved by careful planning and equipment evaluation.

Field personnel who operate the automatic lease assume greater technical responsibilities; thus, individual instructions and some basic knowledge of the equipment's operation are desired.

COSTS

Automatic tank battery equipment	$ 2,915
Well flow control equipment	3,695
Separator float control equipment	618
Electrical distribution system	1,413
Labor	2,415
Transportation	97
Other expense	444
Total	$11,597

ACKNOWLEDGEMENT

The author wishes to express his appreciation to Gulf Refining Co. for permission to publish this paper.

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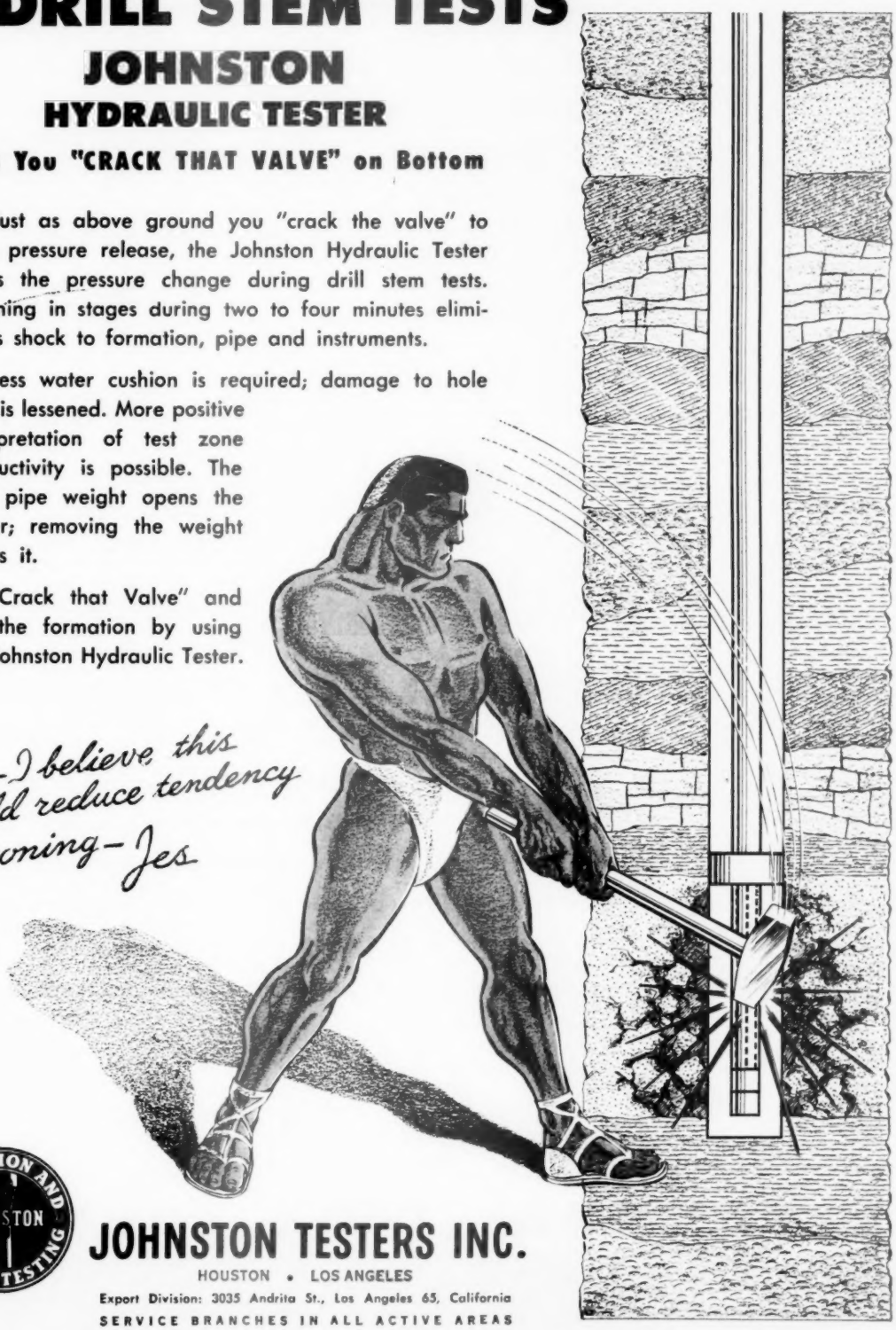

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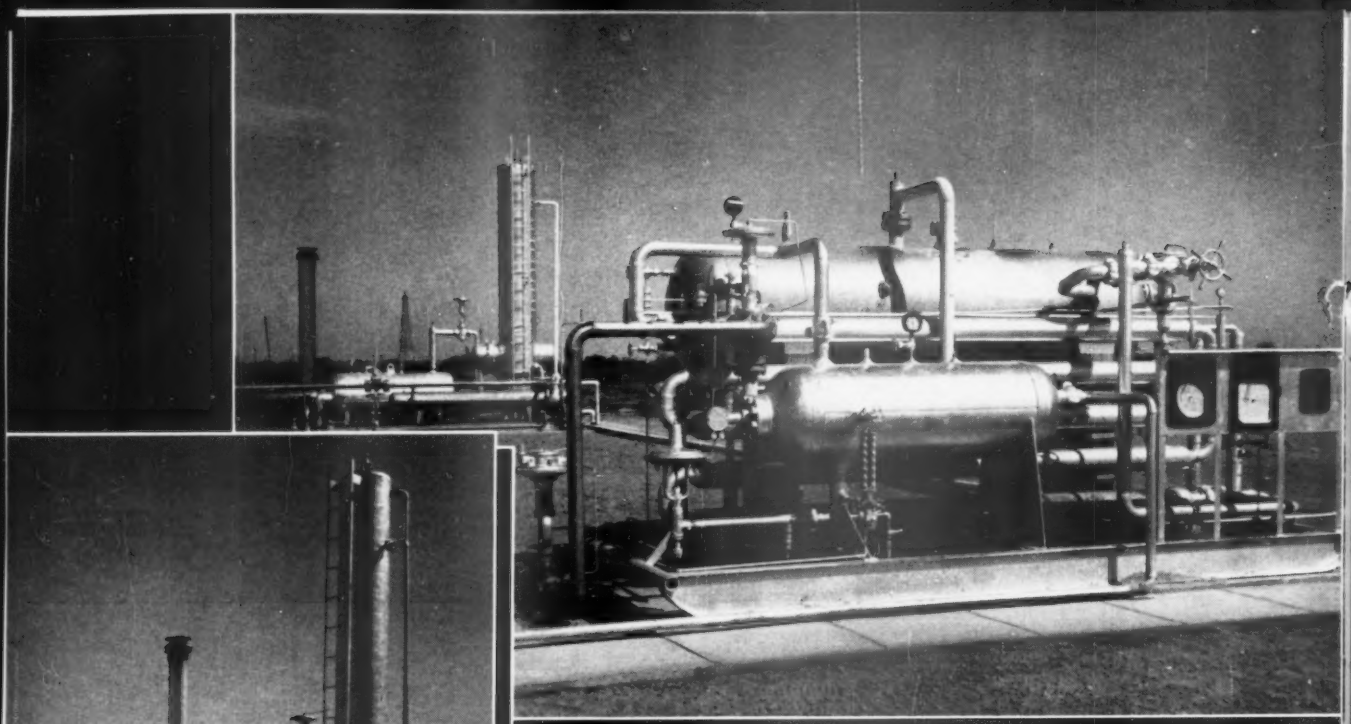

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A SIMPLIFIED CEMENTING TECHNIQUE for RECOMPLETION OPERATIONS

T. A. HUBER
G. H. TAUSCH
J. R. DUBLIN III
MEMBERS AIME

HUMBLE OIL & REFINING CO.
HOUSTON, TEXAS

T. P. 3739

ABSTRACT

Simplified equipment and techniques have been developed to permit cementing a completion interval in a well and recompleting higher, lower, or at the same depth in such a manner as to:

1. *Eliminate the need for a conventional drilling or workover rig.*
2. *Eliminate mud and other cement contaminants which have long interferred with ideal cementing.*
3. *Eliminate need for drilling out cement.*
4. *Provide a more satisfactory recompletion.*
5. *Provide a more economical recompletion.*

This technique involves the use of a small-diameter, lightweight, tubing extension which is run on a wireline and set in a landing nipple previously installed in the tubing string. Low squeeze pressure and small cement volumes, with their attendant cost reduction, are successfully used when wells are completed and reworked with salt water or other penetrating fluids.

Relatively low-water-loss cement is an integral component of the technique which provides that excess cement be reverse-circulated from the well to leave the casing void of cement when recompleting lower or in the same interval. Substantial cost reductions are realized by using the simplified or low-pressure cementing technique, and the ratio of successful squeeze-cement operations has been increased.

[1]References given at end of paper.

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INTRODUCTION

Squeeze-cementing or recementing is the act of filling a channel behind casing or filling holes purposely placed in the casing. To obtain a satisfactory squeeze-cement job, it is necessary only to fill the channel or the perforation holes with a cement filter cake and to allow it to harden in that position. In the past, the presence of mud in a well has been considered the chief deterrent to obtaining a good cement bond and satisfactory cement job; however, late developments in squeeze-cementing have made it possible to eliminate cement contamination or interference. Since it is possible to form a cement filter cake with a small pressure differential, squeeze-cementing with high pressures may not be necessary in most cases.

The amount of cement needed to fill the annulus about the casing and even to fill part of the casing, if necessary, is generally small in quantity. Use of low squeeze-cementing pressures and small quantities of cement provides the following advantages:

1. Longer effective life of well tubing, casing, and other equipment; and less chance of costly equipment failure due to excessive pressure.
2. Monetary savings effected by elimination of retainers and specal squeeze-cementing tools.
3. Monetary savings effected by use of small quantities of cement and fewer squeeze-cementing operations.
4. Future surface squeeze-cementing equipment may be smaller and more economical to operate and maintain.

To deposit cement about the casing while squeeze-cementing with low pressure, it is imperative that no mud filter cake be present in the cavities or channels to be filled with cement. To accomplish this, the well must be perforated with clean fluid in the casing and must be killed or reworked with a penetrating fluid, or fluid not depositing a filter cake.

When salt water or other clean fluid is used as a workover fluid, it is often dangerous to pull tubing from a well; therefore, a technique has been developed which does not require removal of the tubing. Tubing is originally set above the anticipated producing intervals, with a landing nipple near its lower extremity. A tubing extension of one-inch aluminum pipe is used to extend the effective length of the tubing for the purpose of conducting cement slurry to the proper location while squeeze-cementing. This extension is suspended from a wireline mandrel which is lowered into or retrieved from the landing nipple with a small steel wireline.

This new technique of squeeze-cementing by using the retrievable tubing extension precludes the use of a bit to remove set or hardened cement. It is often necessary to use a special cement which will form a filter cake of dehydrated cement between casing and formation face and will still remain sufficiently fluid within the casing to be reverse-circulated from the well.

THEORY

The conventional method of perforating with drilling mud in the casing, and of unavoidably having mud ahead of cement when squeezing cement into perforations, necessitates the use of high squeeze pressures to force mud or mud filter cake into the formation or formation fractures so that the cement slurry may enter the perforations. It has never been shown that this action of squeezing large quantities of drilling mud and cement into the formation has enhanced the producing characteristics of an oil or gas well. However, it has definitely been demonstrated that cement does not adhere tightly to a formation which has previously been flushed with drilling mud.[3]

Fig. 1 illustrates the possible condition existing when a well perforated in an oil-producing sand produces water from a lower sand through a channel behind the casing. If conventional techniques were used to cement such a channel, water in the channel would be replaced with mud before cementing or during the act of cementing. This mud in the channel could be replaced by cement only by rupturing the formation below the upper oil sand and forcing mud into the resulting fracture. Were the upper oil-producing sand to rupture and allow cement to enter, the channel would be by-passed and not repaired. If this second operation took place, the well might again produce water when reperforated in the oil sand. Water production would be temporarily halted, however, if a small cement cap entered the channel.

If the new technique of low-pressure squeeze-cementing were used, salt water would be used as a recompletion fluid and water in the channel would be replaced with cement. Only pressure sufficient to force water into the water sand need be applied while cementing. The water or oil sand need never be ruptured. Cement is given every chance to bond with the formation and casing and dehydrate in a channel cleaned by water production. The technique of low-pressure squeeze-

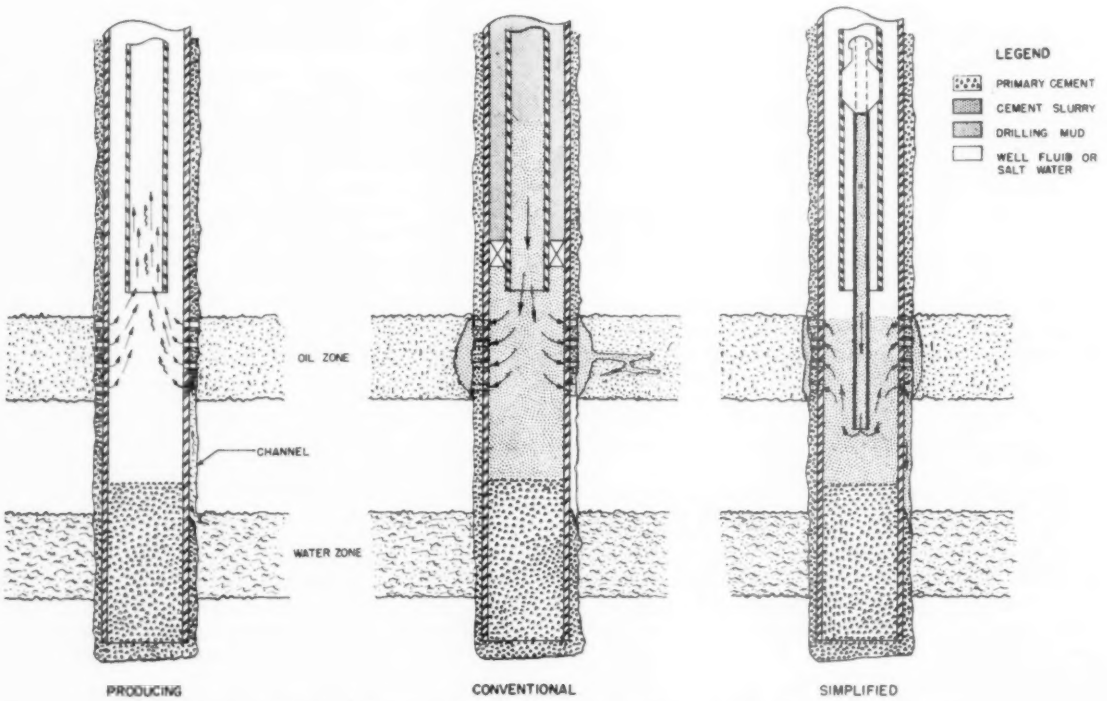

FIG. 1 — FILLING A CHANNEL BEHIND PRODUCTION CASING WITH CEMENT BY USING CONVENTIONAL AND LOW-PRESSURE SQUEEZE TECHNIQUE.

cementing without the use of mud will repair a channel in communication with the perforated interval when the channel is above or below the productive oil zone.

Squeeze-cementing is also often the means of controlling excessive gas and salt water production from an oil-producing zone. The low-pressure technique of squeeze-cementing entails the deposition of cement filter cake in each perforation hole. The conventional squeeze-cementing technique requires that the formation be ruptured or that a high pressure be applied so that the drilling mud in each perforation hole may be replaced with cement.

The fact that it is extremely difficult to create an individual fracture through each perforation hole, or to replace the drilling mud in each perforation hole with cement, explains the poor success ratio when drill-stem testing conventional squeeze-cementing jobs. Once the perforation holes have been sealed and the producing interval has been reperforated higher or lower, exclusion of gas or salt water is actually dependent on low vertical permeability within the formation due to shale, bentonite, or other barriers.

The formation of an effective impermeable layer of cement within the producing sand, which prevents the vertical migration of gas or salt water, is probably very rare. In considering the formation of an effective horizontal or bedding plane cement pancake, the following points are of interest:

1. Laboratory and field proof that numerous formation fractures occur at a high angle.[2]
2. Arc of cement pancake from perforation hole generally 140° to 270°, thereby reducing chance of obtaining 360° pancake.[1]
3. Ability to obtain fracture in desired location between gas or water and oil extremely limited.[1]

In those reservoirs where good vertical permeability is present and producing rates control gas- and water-oil ratios, conventional squeeze-cementing techniques have generally been unsuccessful. The new low-pressure squeeze-cementing technique would likewise be ineffective; however, it should be possible to restore production after each squeeze job, which is sometimes impossible after numerous conventional cement jobs.

To squeeze-cement a producing zone and reperforate a portion of this same zone by the conventional techniques, it is necessary to drill hard cement out of the casing. There is a growing feeling that the action of a drill bit may be detrimental to an otherwise successful cement job. The pounding of the bit against the casing while drilling out excess cement may fracture the small pieces of set cement in the perforation holes and in the channels, particularly if such cement is backed up with a cake of mud.

In the simplified technique, the tubing is left in place and excess cement is reverse-circulated from the casing to a point below the perforations, thus eliminating the drilling out of excess cement. This may be an added reason for a successful squeeze-cement job with this technique.

SURFACE EXPERIMENTS

It was considered that a relatively low-water-loss cement of retarded set time would be necessary if excess cement were to be reverse-circulated from the casing to a point below the perforations. A series of surface tests was initiated to determine if these predictions were correct and to determine which cements would be suitable. Test chambers were designed to simulate actual well conditions as closely as possible.

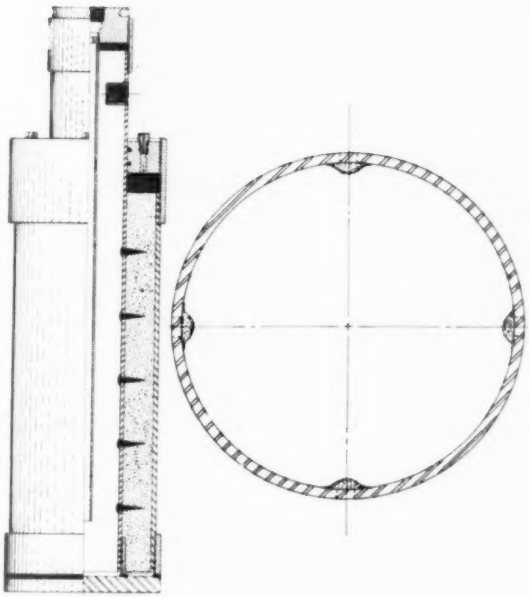

FIG. 2 — (left) SQUEEZE-CEMENTING TEST CHAMBER.

FIG. 3 — (right) CROSS SECTION OF CASING SHOWING CEMENT FILTER CAKES OVER EACH PERFORATION HOLE.

Each chamber shown in Fig. 2 consisted of a 7-in. OD casing nipple set concentrically inside a shorter 13⅜-in. OD casing nipple. Both ends of the larger nipple were sealed against the inner nipple by means of a sealed upper cap and a lower plate. The lower 1 ft of 7-in. OD nipple was blank and the next 2 ft were perforated with six ½-in. holes per ft. Above the sealing cap, a 2-in. regular side outlet was provided to allow attaching of a reversing line during cementing operations. A steel 7-in. OD cap was tapped to receive a regular cementing connection on the upper side and 1¼-in. wash pipe on the lower side. The 1¼-in. pipe extended below the perforation holes to simulate a small tubing extension. Small screen cones, 2½ in. long with a ½-in. diameter, were made of 30-mesh bronze screen wire to approximate the size and shape of jet perforation holes. The annular space between the 7-in. OD and 13⅜-in. OD nipples was filled with fine sand for each test.

The first test was performed with a conventional neat cement slurry having a water loss of about 650 cc per 30 minutes when taken against a sand bed in an API mud filter press. A maximum squeeze pressure of 1,000 psi was maintained for 30 minutes. At the end of this time, cement could not be reverse-circulated from the test chamber and was found to be in a tightly compacted state. Dehydration of all cement in the chamber was evident. As a result of this test, conventional neat cement slurry was considered unsatisfactory for this use, since it would not retain sufficient fluidity within the casing after squeeze-cementing.

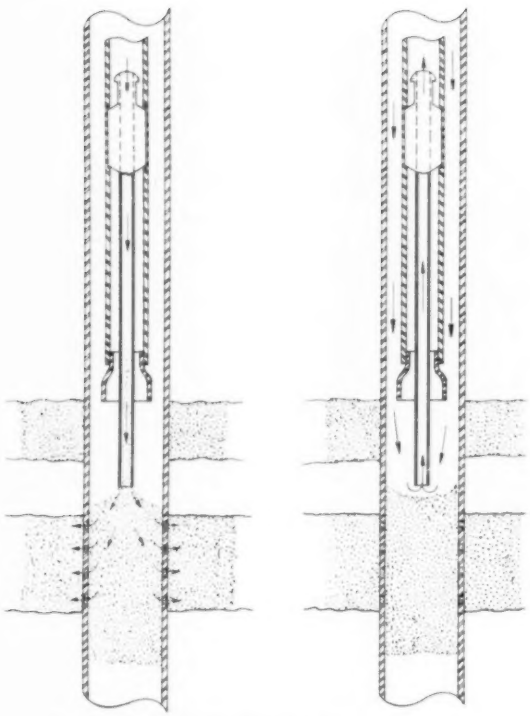

FIG. 4 — BASIC PROCEDURE FOR PLUGGING A NONCOMMERCIAL ZONE.

The remaining tests were performed with three cement slurries having a relatively low water loss. The water loss of the three cements, when taken against a sand bed in an API mud filter press, varied between 65 and 120 cc per 30 minutes. The slurry weights varied from 12 to 14.1 lbs per gal. Each cement was used in the test chamber with a squeeze pressure of 1,000 psi to 1,200 psi and was easily reverse-circulated from the chamber after pressure was maintained from 15 to 55 minutes.

Visual inspection of the test chamber showed cement filter cake formed in each perforation hole and extended into the 7-in. casing in shapes resembling rivet heads, as shown in Fig. 3. The cement filter cake protruding into the casing had been formed within a 15-minute interval while maintaining maximum squeeze pressure. The increase in size of the filter cake was extremely small when the time for maintaining this pressure was extended to 55 minutes. The amount of water used to reverse-circulate cement from the chamber was varied from 3 bbls to 60 bbls to determine if this cement filter cake could be eroded from inside the casing by the reversing fluid. The reversing rate was also varied, with no visible sign of filter cake erosion.

Each of the three cements was allowed to set in the test chamber after squeeze-cementing operations, and a pressure of 1,000 psi was applied into the annulus containing fine sand. Although thread leaks in the lower end of the chamber indicated pressure continuity through the annulus, each cemented hole maintained a satisfactory seal. The nodes of cement filter cake were mechanically removed from inside the 7-in. nipple prior to one pressure test to determine if these nodes were essential. The cemented perforations again held satisfactorily.

Since cement filter cake is permeable and in actual well operations a differential into the formation would exist because of the hydrostatic head of salt water above the perforations, it was necessary that a test be run to determine if the cement filter cake would remain permeable after setting. An API mud filter press was filled with cement and a cement filter cake formed. A water hose was then connected to the top of the press and water allowed to run through the cement filter cake. After the cement filter cake had set, generally from six to eight hours, the flow of water through the cake stopped and the cement, for all practical purposes, appeared to be impermeable.

Although the three cements with a relatively low water loss appeared to be satisfactory for this type of squeeze-cementing, it was decided to use only one of these cements for field work. Modified cement (normal Portland cement containing calcium lignosulfonate and bentonite) was selected because of its economy, availability, and the field personnel's greater familiarity with this cementing composition.

SUBSURFACE EQUIPMENT FOR SIMPLIFIED SQUEEZE-CEMENTING

It was possible to reduce the cost of squeeze-cement-

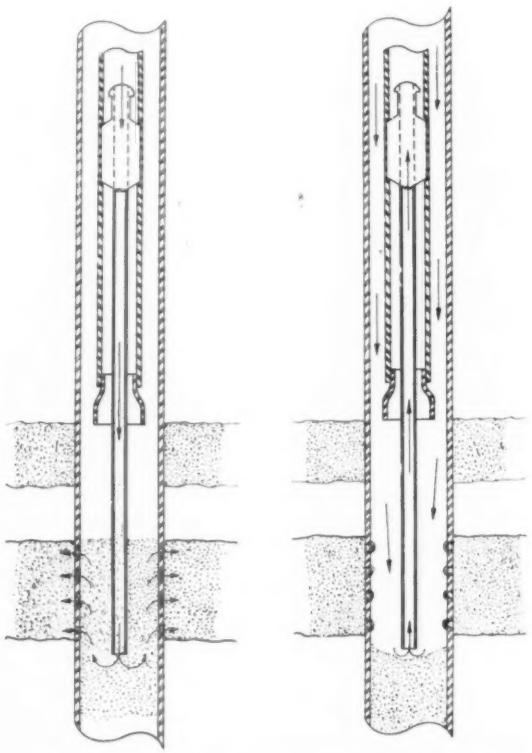

FIG. 5 — BASIC PROCEDURE FOR SQUEEZING OFF EXCESSIVE GAS OR WATER.

ing by increasing the success ratio, eliminating special squeeze tools, and decreasing the amount of cement used. Recompletion costs could be further reduced by eliminating the rig entirely or by reducing the setting time and "waiting-on-cement" time, as well as trip time necessary to use cement retainers and drill bits. Use of a cement with low water loss and added retarding agents which keep this cement fluid during the squeezing operations precludes a reduction of rig time during cement setting time and "waiting-on-cement" time, and emphasizes the need to eliminate the rig entirely.

It is possible to eliminate a rig while squeeze-cementing by completing a well with the proper tubing setting and by using a retrievable tubing extension. This tubing extension, made of 1-in. aluminum pipe, is suspended from a landing nipple near the lower extremity of the tubing during squeeze-cementing operations. The extension is lowered into place and retrieved with an 0.082-in. wireline; however, the wireline is not attached to the extension during cementing operations. The longest extension used to date is 1,000 ft; circulating pressures may become excessive if considerably longer extensions are used. Reverse-circulation with salt water, using the cementing pump, aids in running and retrieving long extensions without exceeding the strength of the small steel wireline.

All cementing with this new simplified method is accomplished by applying Bradenhead squeeze pressures. The basic procedures used in plugging a non-commercial zone or squeezing off excessive gas or water to allow reperforating lower or in the same interval are shown in Figs. 4 and 5. Cement is found approximately 1 ft below the bottom of the tubing extension setting after squeeze-cementing by either of the above procedures. Since squeezing pressures, cement volumes, and tubing settings are not varied for either technique, selection of the length of the tubing extension controls the top of the cement left in the casing and accordingly the amount of cased hole left vacant for reperforating.

By either technique, cement is displaced down the tubing and the well casing valve is closed prior to emergence of cement from the lower end of the tubing. This makes it necessary to force several barrels of salt water into the formation ahead of the cement. Should the permeability of the formation restrict this salt water displacement to a slow rate at the low pressures used, cement may be displaced around the tubing extension prior to squeezing, thus reducing the quantity of water to be displaced.

If a gas-lift well is completed in a manner to allow this method of cementing or if a well is set up in preparation for future gas lift as well as the simplified method of cementing, the landing nipple for the tubing extension is located above the lower retrievable gas-lift valve mandrel. This lower mandrel is generally one tubing joint above the production packer. The upper retrievable valve mandrels are located at the customary positions in the tubing to allow efficient gas-lifting, and contain dummy valves during cementing operations. The lower mandrel is left open to permit communication between tubing and casing and to by-pass the packer while squeezing. The tubing setup and direction of flow while cementing are shown in Fig. 6.

In gas wells, a production packer is used to keep excessive pressure off the casing while producing. A special circulating port is located between the landing nipple and the packer. The circulating port may be opened or closed with a wireline to permit communication between casing and tubing.

Wells may also be set up with a landing nipple which seats the tubing extension as well as a rod pump. A small pulling unit is used to remove and replace the pump and rods during remedial operations.

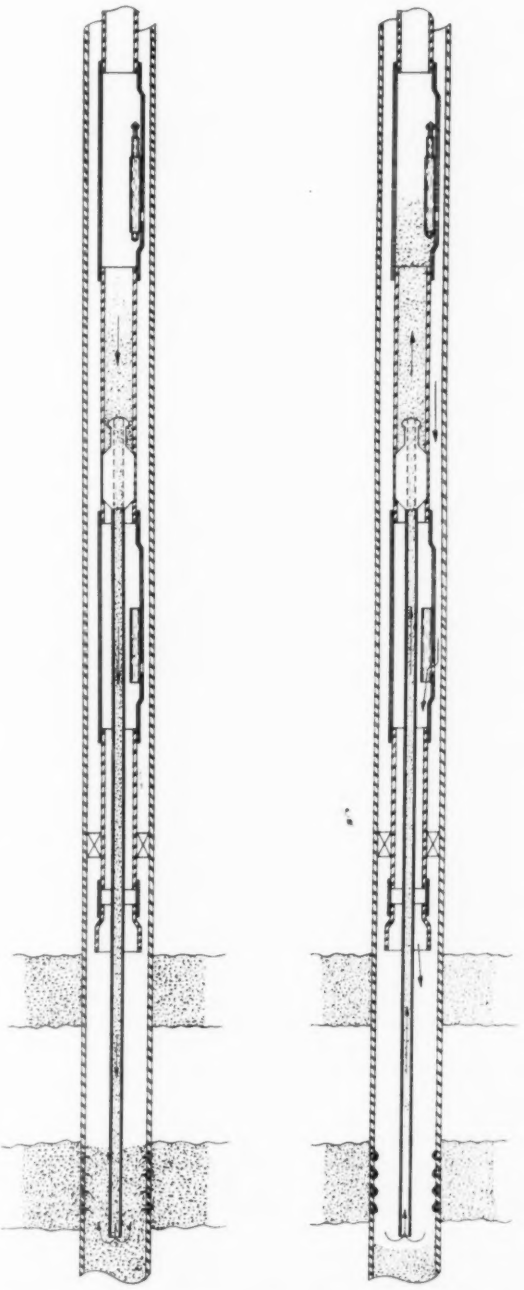

FIG. 6 — TUBING SETTING SHOWING GAS-LIFT EQUIPMENT, PRODUCTION PACKER, AND DIRECTION OF FLOW DURING SQUEEZING AND REVERSING.

To complete a well in preparation for the simplified method of cementing, the following conditions must be satisfied:

1. Tubing must be approximately full-opening to permit use of the tubing extension and tubing-type perforator.
2. Tubing mut be pressure-tight above landing nipple. Communication between tubing and casing must be provided below landing nipple.

FIELD RESULTS

The simplified method of squeeze-cementing without a rig, using low squeeze pressures and small volumes of modified cement, has been used in field work to seal off noncommercial intervals, allowing wells to be reperforated in the same, higher, or lower intervals. Surface squeeze pressures have varied between 1,200 and 2,500 psi, while the amount of cement left in place after cementing has varied between two and 15 sacks. The amount of slurry currently being mixed for each job ranges from 10 to 15 bbls. The magnitude of squeeze pressure has shown no effect upon the success of the cementing operations. As a test of a successful squeeze-cement job, wells have been gas-lifted, pumped, or swabbed dry after cementing, to place the full formation pressure against the cemented perforations.

One 3,700-ft well in East Texas was cemented with modified cement by using a surface squeeze pressure of 600 psi. The well had been completed with salt water and salt water was used as a workover fluid. A small pulling unit was used during this operation, since salt water could be used safely and since the cost was small. After squeezing, cement was reverse-circulated from the liner to a point 60 ft below the perforations. The workover fluid was swabbed from the well and no fluid was recovered from the cemented perforations. The well was then reperforated lower.

A 9,300-ft well in the Texas Gulf Coast was plugged with nine sacks of modified cement using the tubing extension. A maximum squeeze pressure of 1,700 psi was used. Upon perforating higher in the same sand, the well produced 25 per cent salt water. The success of the plugback job was questioned, and this well was squeezed in the conventional manner with a maximum and final pressure of 4,700 psi using 60 sacks of slow-set cement. Upon reperforating in the same zone, the well again produced salt water, proving the low-pressure squeeze technique to be as effective as the conventional technique. Later recompletion in a higher interval of the same sand eliminated water production.

Perforations in a 5,000-ft gas well in the Texas Gulf Coast were squeezed by this new technique, the cement job was tested, and the well was reperforated in a sand underlying the former producing interval. The well flowed with a 3,500-cu ft/bbl gas-oil ratio, causing doubt as to the effectiveness of the previous squeeze job. Perforations were squeezed in the conventional manner and the interval was reperforated. The well flowed with a high gas-oil ratio, again proving the simplified method of cementing to be as effective as the conventional method. Later reservoir analysis proved this high-ratio zone was not in communication with the upper gas zone.

The present trend toward small cement slurry volumes of about 10 bbls will allow lower squeeze pressures in the range of 1,000 to 1,200 psi. This lower squeeze pressure should extend the effective life of casing, while the Bradenhead squeeze technique exposes the tubing to a low pressure differential and allows a correspondingly longer useful life.

The elimination of a rig while cementing and performing other operations has brought about a substantial reduction in workover costs. A wireline workover involving squeeze-cementing and reperforating generally costs $1,200 to $2,000, depending on well conditions. However, the cost of this method is almost independent of depth, which is not true of conventional workovers. Use of the tubing extension and tubing-type perforator has reduced the cost of workovers performed with these tools by 40 to 60 per cent. Costs may also be reduced when rigs are used in reworking wells with salt water by using the low-pressure, low-volume method of cementing, since squeeze tools and rig time consumed while drilling cement are eliminated.

FRACTURED FORMATIONS

In the process of squeeze-cementing by the simplified method, the formation was accidentally fractured or opened in four wells, although low squeeze pressures were used. A dry test could not be obtained in one of these wells. This well had been squeezed with 1,800 psi maximum surface pressure, and excess cement was reverse-circulated from the well to a point below the perforations. Several cubic feet of cement fill-up was discovered in the casing below the perforations after the cement had set, indicating a cement flowback. This well was successfully repaired by a second squeeze job, using the simplified method, without rupturing the formation. One other well also exhibited a cement flowback.

When complete dehydration of the cement slurry is not obtained within a fracture, the fluid cement slurry tends to re-enter the well bore as the fracture closes after the squeeze pressure is released. Because of the low filtration rate of modified cement, the deposition of cement particles upon the face of the formation fracture is slower when this type cement slurry is used. It is necessary, therefore, to use a "hesitation" or stage squeeze to obtain a final squeeze pressure greater than the "breakdown" pressure without extending the fracture. The maximum squeeze pressure must be maintained for a longer period of time when a formation has been fractured to permit complete dehydration of cement within the fracture.

Two of the wells in which the formation was fractured did not exhibit a cement flowback. In both cases the maximum squeeze pressure was maintained for a longer period of time, and 1,000 psi pressure was placed on the well after cementing operations were complete. This action evidently maintained the cement in position until it was dehydrated or until its viscosity was too high to allow movement.

Formations with Low Permeability

The second and only other cementing failure occurred in a well which had been squeezed to a maximum pressure of 2,500 psi. This maximum pressure had been maintained for 10 minutes and cement was reverse-circulated from the casing to a point below the perforations. When this cement job did not stand up to a dry test, the well was again squeezed to 2,500 psi and the pressure was maintained for 20 minutes before reverse-circulating excess cement. After the second

squeeze-cement job, a dry test was obtained.

Examination of the electric log displayed a formation tight streak through the perforated interval. It was decided that insufficient time had been allowed for the deposition of cement filter cake within the perforation holes through the tight zone. High water-injection pressures during the second cement job and the success of this job seem to substantiate this decision.

FUTURE DEVELOPMENT WORK

Although field work to date has been gratifying, some minor problems have arisen as use of the simplified low-pressure squeeze-cementing technique has increased. The following problems are now being investigated, or will be studied in the near future:

1. Length of time squeeze pressure must be maintained to form satisfactory cement filter cake on low-permeability formation.
2. Method of treatment when a formation is unavoidably fractured. It may be necessary to discontinue the pumping of cement immediately. When allowing cement to set, pressure may be placed on the well. A recording gauge will be used to detect the dissipation of this pressure or to denote any buildup of pressure due to thermal expansion of well fluids.
3. Better field cement-mixing techniques with smaller surface cementing equipment.
4. Squeeze-cementing wells that have been completed with mud, have produced large quantities of fluid, and have been circulated and reworked with salt water. It must be determined if mud filter cake contained in the perforation holes after the original completion will be detrimental to a successful squeeze-cement job.
5. Method of reworking wells with a formation pressure gradient greater than 0.5 psi per ft without allowing drilling mud to contact the formation. This may be accomplished by lubricating the tubing extension into the tubing under pressure or by using a destructible plug at the lower end of the tubing as a seal while running the extension. Cement will then be forced into the well under pressure and excess cement will be reverse-circulated from the well with mud. The mud left in the well while cement is setting will be replaced with water prior to reperforating.

SUMMARY

Results obtained from laboratory studies and field use of the simplified cementing technique have led to the following conclusions:

1. Successful squeeze-cement jobs can be performed with low pressures and small volumes of cement if a clean fluid such as salt water is used as a completion and workover fluid. It is not necessary to fracture the formation while squeeze-cementing, nor is the surface squeeze pressure an indication of a successful cement job.
2. Hard or set cement need not be drilled from the casing after a squeeze job. The use of a cement slurry which remains fluid within the casing permits the casing to be cleaned after the squeeze-cement job by circulating all cement from the well to the depth desired. A low-water-loss cement should be used so that the slurry within the casing will remain fluid during squeeze-cementing operations.
3. The simplified low-pressure squeeze-cementing technique may be performed without rigs, special squeeze tools, or large cement pump trucks, thus making possible a large reduction in recompletion costs.
4. Developments in this method are promising and should be continued to provide better cement mixing with smaller equipment, more information concerning squeeze-cementing, and a means for handling wells having abnormal formation pressures.

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EFFECTIVENESS of GUN PERFORATING

T. O. ALLEN
MEMBER AIME
J. H. ATTERBURY, JR.

HUMBLE OIL & REFINING CO.
HOUSTON, TEXAS

T. P. 3740

ABSTRACT

Laboratory and field tests during the past five years indicated considerable variation in the penetrating power of commercially available gun perforators. Many of the guns which achieved inadequate penetration in these tests have since been improved. However, recent productivity tests indicated the possibility of inadequate penetration or, at least, ineffective penetration in some wells.

Laboratory experiments under simulated well conditions have demonstrated considerable plugging of the perforations, apparently as a result of factors associated with the shooting process and/or the drilling mud in the well at the time of perforating. The restrictions to flow per unit of hole depth caused by this plugging appears to be greater for jet perforators than for bullet guns of comparable diameter; however, because of the greater depth of penetration obtained with the jet guns, the total flow rates appear to be approximately equal. Limited testing with an experimental shaped charge suggests that less shot hole restriction and greater flow rates may result from larger-diameter perforations or other factors related to charge design.

INTRODUCTION

Gun perforating has been accepted for a number of years as a routine well completion method which is often preferred since it permits more selective operation of producing zones. Nevertheless, questions have continued to arise as to the effectiveness of the communication paths established between the productive formation and the interior of the casing. The basis for these questions has generally been failure to obtain anticipated fluid production rates through gun perforated completions in specific wells. These low productivities, together with the frequent recovery of bullets from well bores, were considered strong evidence of inadequate penetration.

Laboratory investigations of the penetration performance of many of the bullet guns available as late as 1948 gave support to these indications. Subsequent electrical analog studies[1, 2, 3] indicated that the depth of penetration required to provide productivities equivalent to open hole was beyond the capacity of most bullet perforators evaluated in the early laboratory penetration tests.

These results, together with the advent of the shaped charge in the field of oil well perforating, stimulated the interest of both oil operators and service companies in gun development. Improvements in gun design resulted in jet and bullet guns which appeared to be capable of providing sufficient penetration for most perforating jobs. However, some wells failed to yield satisfactory fluid production even after being perforated with the more powerful guns, again raising the question as to the effectiveness of the perforating operation. This fact, together with preliminary shooting into targets prepared with formation cores, indicated that factors associated with the perforating process and/or the fluids in the well bore at the time of shooting may reduce effective formation penetration and thereby decrease well productivity. These laboratory and field data prompted another phase in the investigation of the effectiveness of gun perforating: a program to determine the extent and seriousness of perforation plugging under simulated well conditions.

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office August 5, 1953. Paper presented at the Petroleum Branch Fall Meeting in Dallas, Texas, Oct. 18-21, 1953.

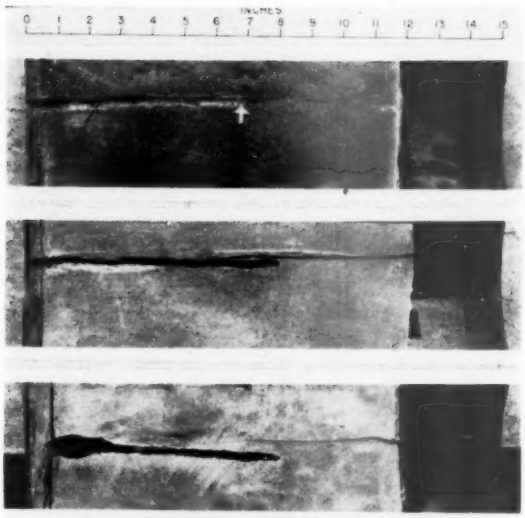

FIG. 1 — EXAMPLES OF JET PERFORATOR PENETRATION (STANDARD JET CHARGE FOR 4-IN. OD GUNS).

The object of this paper is, therefore, twofold: first, to review the analog and laboratory penetration investigations of the effectiveness of gun perforating, and second, to describe in detail the perforation plugging experiments now in progress.

REVIEW OF PREVIOUS INVESTIGATIONS

Penetration tests reported by Oliphant and Farris[4] in 1947 showed that the commercially available bullet perforators tested were capable of penetrating from zero to 2½ in. into the targets used in the experiment. These targets consisted of 5½-in., 17-lb, J-55 casing centrally located in an oil drum and backed up with a thin annular sheath of neat cement supported by either unconsolidated sand or concrete to represent formation.

Independent tests reported by Huber, Allen, and Abendroth[5] in 1950 confirmed these results, and presented additional information on improved bullet guns as well as jet perforators available at that time. These tests were performed in a pressure chamber with both gun and target submerged in cold water under pressures ranging from zero to 4,500 psi. The targets employed consisted of 0.435 in. of flattened N-80 steel casing supported by about 12 in. of neat cement having a tensile strength of 500 psi. A single-shot gun representing a 4-in. OD commercial perforator was fired into an individual target for each test. It may be noted from the results of these tests shown in Fig. 1 and 2 that the total penetrations are of the magnitude of 7½ in. for the shaped charges and 1 to 7 in. for 5 of the 10 bullet guns tested. Since the penetrations achieved by the other five bullet guns were less than 1 in., the results are not shown in the illustration.

Additional tests conducted on the surface with 4-in. OD and larger bullet guns with the same type targets indicated increased penetration with increased gun diameter. These results are illustrated in Fig. 3 for a premium-priced bullet gun. More recent penetration tests with a modified design of one of the bullet guns which achieved less than 1 in. of penetration in earlier tests indicate penetrations of 5⅞ in. for the 4⅛-in. OD gun, and 8 in. for the 5-7/16-in. OD gun.

The relative prductivity of wells with perforated casing has been treated mathematically by Muskat[6] and also through electric analog studies by McDowell and Muskat[7] and by Howard and Watson.[2,3] These data showed that the productivity for perforated casing completions could equal or exceed the productivity of open hole completions under idealized conditions represented in the analog studies. For example, a relative productivity equal to open hole is reached with perforations 6 in. deep in a 6-in. diameter well with a shot density of 5.5 holes per ft. using ½-in. diameter holes, or 6.5 holes per ft. using ¼-in. diameter holes.

Under the analog conditions the well diameter corresponds to the diameter of the hole drilled in the formation and the depth of the shot hole corresponds to the penetration into the formation. When comparing this optimum formation penetration of 6 in., or a total penetration of 7 to 8 in., including the casing and cement sheath, with the laboratory penetrations of zero to 2½ in. and zero to 7 in. reported above, it is obvious that most of the 4-in. and smaller bullet guns available as late as 1948 were incapable of the

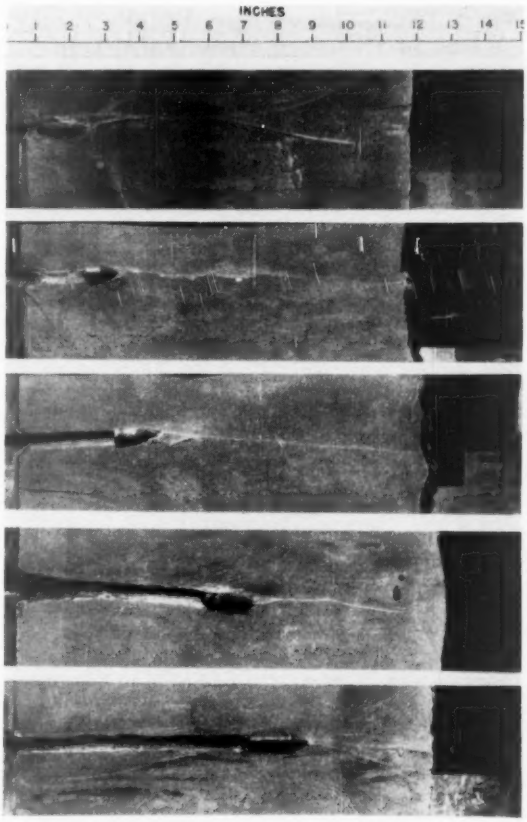

FIG. 2 — EXAMPLES OF PENETRATION FOR 4-IN. OD BULLET PERFORATORS.

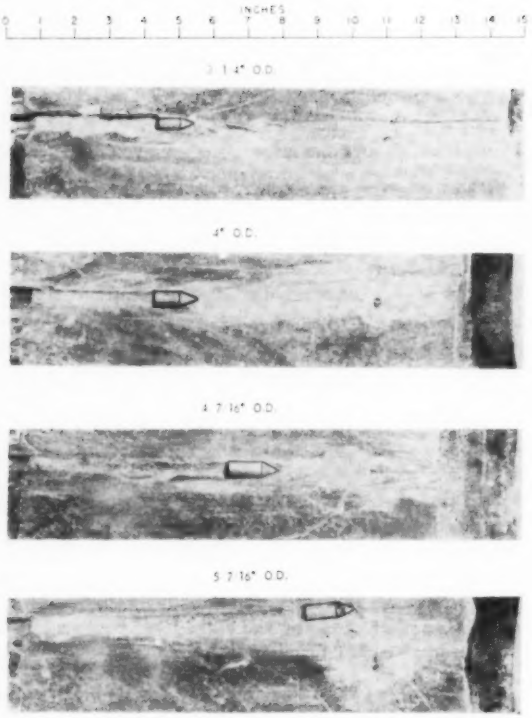

FIG. 3 — EXAMPLES OF PENETRATION FOR VARIOUS SIZES OF A PREMIUM PRICED BULLET GUN.

theoretically desired penetration. However, the 7½-in. penetration of the 21 gm shaped charges and that of the new or improved bullet guns appears satisfactory in a similar comparison.

An examination of the data presented by Lewelling[7] in 1952 regarding penetration into hard limestone cores showed significantly less penetration than was previously obtained with the same bullet gun fired into neat cement targets by other investigators; however, jet penetration was not reduced in the same magnitude by the hard limestone. Information obtained in the plugging investigations reported in the following section tends to support Lewelling's findings that bullet penetration is more adversely affected by hard formations than jet penetration.

INVESTIGATIONS OF PERFORATION PLUGGING

This investigation had as its objectives the determination of the effect of both the jet and bullet perforating processes on various types of formation, and how this effect is influenced by well conditions.

In simulating well conditions, the test well must be equipped with casing cemented adjacent to a formation which has controlled hydrocarbon and salt water saturations as well as reservoir temperature and pressure. The casing must be filled with a usual well completion fluid having the desired well temperature and pressure. In addition, the pressure differential between the formation and the well bore should be controlled during the shooting, well cleaning, and producing phases of the operation.

DESCRIPTION OF LABORATORY EQUIPMENT

The laboratory facilities which had been used for the competitive penetration tests reported by Huber, Allen, and Abendroth,[5] were expanded to accommodate testing under simulated well conditions. The schematic diagram in Fig. 4 shows the layout of test equipment employed. It may be noted that the test chamber in the center of the diagram contains an inner cylinder, or target, with a formation core cemented inside. The upper face of this target represents the well casing, and the single-shot test gun above the target is representative of a commercially available 4-in. OD bullet or jet gun. Both the target and gun are submerged in the mud being employed in the simulated well completion. The pressure control system on the right makes up a reservoir system for simulating formation pressure when used in series with the target, and provides the well fluid pressure when used in series with the test chamber. The hot water circulating system shown to the left of the test chamber in Fig. 4 supplies the heat required to maintain the desired well and reservoir temperature. The mud system shown directly above the hot water circulating system provides the equipment for mixing and handling the well fluid.

The mud system consists of a mixing tank, a portable ¾-hp mixer, and a positive displacement pump capable of handling fluids with a high viscosity and high solids content. The hot water circulating system in-

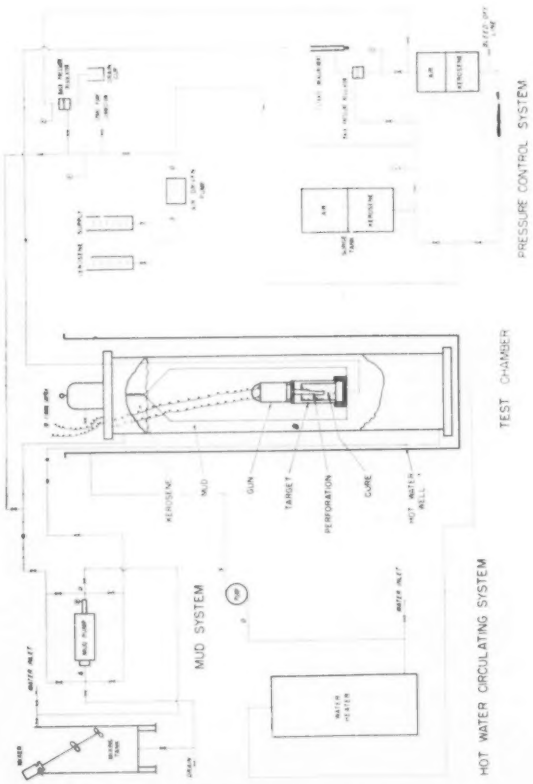

FIG. 4 — SCHEMATIC DIAGRAM OF GUN PERFORATOR TESTING SETUP.

cludes three thermostatically-controlled heaters, pumps, and a hot water well in which the test chamber is submerged. Temperatures up to 200°F can be maintained to within one to two degrees with this equipment. The pressure control system is comprised of an automatically-operated, air-driven pump, two back-pressure regulators, and sufficient additional instrumentation to maintain desired pressures and pressure differentials. The test chamber, constructed from 16-in. OD, 13½-in. ID, steel pipe, has an inside length of 100 in. between the two removable heads, which are equipped with O-ring seals.

The target, as stated previously, consists of a steel case with a core cemented inside. This case is made from 4½-in. OD, 16.6-lb drill pipe threaded on one end and with a mild steel plate representing the well casing welded on the other end. This plate is ⅜-in. thick for bullet targets and 1 in. thick for the jet targets. Since these tests were not designed primarily to compare penetrations, the added thickness of steel is used for the jet targets to insure against the perforation reaching too near the open face of the core.

Hydromite, a gypsum cement containing resin, is used for the cementing material rather than neat cement because of its greater tensile strength and excellent bonding characteristics. While experimenting with target design, neat cement was tried as the support material for the core, but it was found that its bonding characteristics were inferior to those of Hydromite. Berea sandstone cores were selected for use in these targets because of the availability and relative uniformity of this formation. The cores used were 3½-in. in diameter and 8 in. long, and cut parallel to the bedding plane.

Prior to fabricating the targets, these cores are processed to simulate oil and water saturations approaching those of a producing formation. This is done by drying, evacuating, saturating with 30,000 ppm salt water, and then flooding with kerosene until minimum water saturation is reached. The necessary weights are obtained to calculate porosity and oil saturation. The permeability to oil is measured at this final saturation.

A flow diagram of the equipment used in processing the cores is shown in Fig. 5. This apparatus and the other equipment in the core laboratory is, for the most part, standard laboratory equipment. Some of it is commercially available and part was built for this project.

Discussion of Tests and Test Procedure

The number of variable which might affect this investigation was recognized. Accordingly, the program was planned to first obtain basic data using the Berea sandstone cores, a low pH caustic-quebracho mud, and one set of pressure and temperature conditions, before extending the investigation to include work with other fluids, pressures, and formations. The first phase of testing is nearing completion with Berea sandstone cores with permeabilities in the range of 150 to 250 md, 2,000 psi mud pressure, 1,500 psi reservoir or formation pressure, 180°F well temperature, and caustic-quebracho mud with the following average properties:

Weight, lb/gal	9.5
Viscosity, cps	40
API Filtration Rate, cc	10.3
Initial gel, gm	5
10-min gel, gm	23
pH	7.5
Solids Content, Per Cent	19.7

Single shot test guns representing (a) a conventional 4-in. OD premium-priced bullet gun, (b) a jet gun with a standard 21-gm charge, and (c) a jet gun with an experimental 29-gm charge were used. The experimental charge was designed to give greater shot hole diameter at the expense of some penetration. It has been employed in only a limited number of tests.

To prepare for a typical test conducted under the conditions given above, the target and gun are assembled in a carrier and lowered into the test chamber which has been filled with drilling mud. The reservoir system and test chamber are then pressure tested at 1,500 psi and 2,000 psi, respectively. The chamber and its contents are heated to 180°F over a period of 15 to 18 hours. The reservoir and mud are then raised to test pressures, and the gun perforator is electrically fired, perforating the simulated casing, cementing material, and formation.

With a 500 psi pressure differential into the formation when the gun is fired, the mud follows the bullet or jet stream into the shot hole and a filter cake is laid down as mud filtrate invades the core. This filtration phase of the test corresponds to the period in a well completion between perforating and the time when the differential pressure into the formation is removed by swabbing or displacing the mud with lighter fluids.

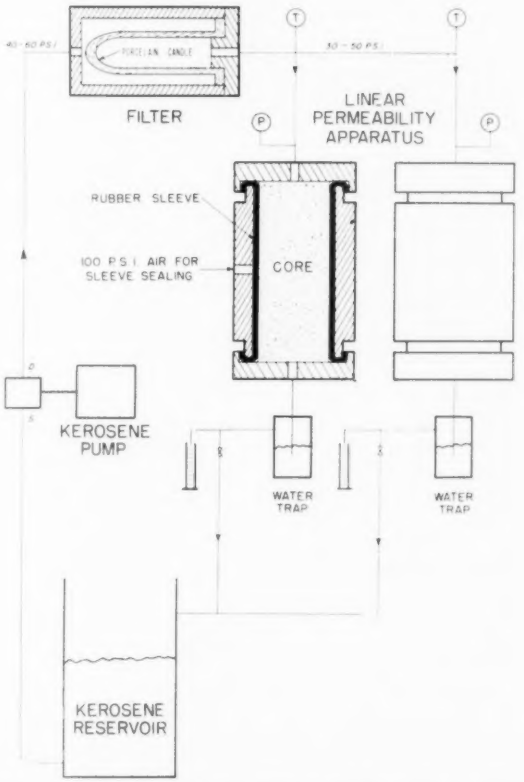

Fig. 5 — Flow Diagram—Permeability Laboratory.

The filtrate entering the core tends to build up the reservoir pressure to that of the mud, but the back-pressure regulator in the reservoir system releases the excess fluid, thereby maintaining a constant reservoir pressure. The volume of kerosene displaced by the filtrate entering the core is measured and the time recorded at prescribed intervals. The filtration phase is continued for a period of approximately 24 hours, the time which might be required on a deep well to come out of the hole with the gun, run the tubing in, and set the Christmas tree.

Following the filtration phase, the mud pressure is slowly reduced below the reservoir pressure to simulate bringing in a well. The purpose of this phase, in addition to simulating well conditions, is to determine the differential pressure required to initiate flow through the perforation.

After this differential has been determined, kerosene is back flowed through the target at a constant pressure differential of 100 to 300 psi. The object of this phase of the test is to flush the mud filtrate from the core with kerosene, simulating the initial production from a well, and to obtain a representative fluid flow rate through the perforation after the well has been cleaned. Within the accuracy of the control equipment, an essentially constant rate is normally attained after flowing 40 pore volumes or less through the core. Backflow is continued at this rate for an additional 40 or more pore volumes. After the target is removed from the well, it is cut open for visual inspection. Appropriate measurements and descriptions are recorded. Then the targets are photographed.

Evaluation of Data

The flow rate through a core of given dimensions depends on the pressure differential across the core, the viscosity of the fluid flowing, and the effective permeability of the formation to the fluid. When the core is cemented in a steel case and perforated as it is in these tests, the flow rate depends also on the diameter and depth of the shot hole, the degree of plugging which occurs, and the condition of the formation adjacent to the perforation.

The flow rate from the formation through the plugged perforation, measured in volume per unit time, reflects the combined influence of these factors. The effect of viscosity, pressure differential, and permeability can be determined by the application of Darcy's Law. The effect of the diameter and depth of the perforation on the flow rate was determined by drilling targets with various diameter holes to successive depths and measuring the flow rate at each depth.

Similar information could be obtained by setting up an electric analog of the target and perforations. However, such an investigation would assume equal formation permeability in all directions. Also, the flow rates obtained might not be as representative as the flow rates obtained with the drilled targets, where the formation bedding planes affect the flow perpendicular to the shot hole. The difference between the flow rate through a perforated hole of a given diameter and depth and the flow rate through the drilled hole of the same dimensions as the perforation and in the same type formation is considered in this paper to be the reduction in flow rate caused by both the perforation plugging and the alteration of the formation around the shot hole by the perforating process. For this to be valid the flow rates must first be corrected to the same viscosity, permeability, and pressure conditions by the application of Darcy's Law as noted above.

For convenience in evaluating the flow data taken in these tests, the flow rate through the core with both faces open to flow is taken as unity. The flow rates through the targets with one face open to flow and the opposite face cemented off, except for either a drilled hole or a perforated hole, are expressed as decimal fractions of this unit flow. These fractions, or ratios, are arbitrarily defined as the flow rate indices for a clean hole and a plugged perforation, respectively. They are designed by the symbols $\bar{q}_c$ and $\bar{q}_p$. Then $\bar{q}_c$ is a measure of the flow which should be obtained through the perforation with no restriction in or around the shot hole, and $\bar{q}_p$ is a measure of the actual flow rate obtained through the perforation.

To convert $\bar{q}_c$ and $\bar{q}_p$ to the corresponding flow rates in volume per unit time, such as cc per second or barrels per day, for a particular pressure, viscosity, and permeability, these indices must be multiplied by the flow rate through the core with both faces open to flow expressed in the desired units, either measured at the prescribed conditions or calculated from Darcy's Equation.

The reduction in flow rate in terms of these indices is, then $\bar{q}_c - \bar{q}_p$, and the per cent reduction, based on the flow rate which should be obtained through the given perforation, is as follows:

$$\text{Per Cent Reduction} = \left(1 - \frac{\bar{q}_p}{\bar{q}_c}\right) 100$$

Test Results

The results presented here are from 22 firing tests simulating individual well completions and conducted during the first phase of the program previously outlined. It should be pointed out that an additional 26 preliminary tests were conducted while experimenting with target design and equipment and in establishing a test procedure which would yield consistent results. A few subsequent tests have also been conducted with other fluids and pressures and Berea sandstone cores in a higher permeability range, but the results from this latter group of tests are too limited to establish a trend and are not reported at this time.

The results will be discussed in terms of (a) the physical characteristics of the perforation and plug, and (b) the flow rates obtained and calculated reductions in flow rates. The average diameter and depth of penetration obtained by each of the three perforators used are as follows:

	Hole Diameter — Inches	Penetration — Inches: Steel and Hydromite	Penetration — Inches: Core	Penetration — Inches: Total
a. Bullet	½	1⅛	1	2⅛
b. 21-gm Jet	¼	2	4¾	6¾
c. 29-gm Jet	½	2	3	5

Bullet penetration shown above was measured to the back of the bullet, and jet penetration was measured to a point ¾ of an inch from the bottom of the hole, since the jet hole usually has a very small diameter near the bottom.

TABLE 1 — FLOW DATA FOR TARGETS PERFORATED IN CAUSTIC QUEBRACHO MUD

Test No.	Perforator	Flow Rate Indices* $\bar{q}_c$	$\bar{q}_p$	Reduction in Flow Rate - % $(1 - \frac{\bar{q}_p}{\bar{q}_c}) 100$
1	4-in. OD Jet with 21-gm charge	1.22	0.39	68
2	4-in. OD Jet with 21-gm charge	1.20	0.44	63
3	4-in. OD Jet with 21-gm charge	1.45	0.39	73
4	4-in. OD Jet with 21-gm charge	1.39	0.43	69
5	4-in. OD Jet with 21-gm charge	1.34	0.53	60
6	4-in. OD Jet with 21-gm charge	1.20	0.75	37
7	4-in. OD Jet with 21-gm charge	0.82	0.40	52
8	4-in. OD Jet with 21-gm charge	1.54	0.35	77
9	4-in. OD Jet with 21-gm charge	1.45	0.32	78
10	4-in. OD Jet with 29-gm experimental charge	1.05	0.86	18
11	4-in. OD Jet with 29-gm experimental charge	1.16	0.88	24
12	4-in. OD Jet with 29-gm experimental charge	0.92	0.68	25
13	4-in. OD Premium Priced Bullet Gun	0.72	0.43	40
14	4-in. OD Premium Priced Bullet Gun	0.81	0.22	73
15	4-in. OD Premium Priced Bullet Gun	0.81	0.48	40
16	4-in. OD Premium Priced Bullet Gun	0.81	0.49	38
17	4-in. OD Premium Priced Bullet Gun	0.76	0.51	32
18	4-in. OD Premium Priced Bullet Gun	0.76	0.53	30
19	4-in. OD Premium Priced Bullet Gun	0.69	0.51	26
20	4-in. OD Premium Priced Bullet Gun	0.76	0.44	42
21	4-in. OD Premium Priced Bullet Gun	0.76	0.68	11
22	4-in. OD Premium Priced Bullet Gun	0.71	0.32	54

*The flow rate indices, $\bar{q}_p$ and $\bar{q}_c$, express the flow rates through the perforation and through a clean hole in the same formation drilled to the same dimensions as the perforation as decimal fractions of the flow rate which would be obtained through the unperforated core with both faces open to flow.

A comparison of these penetrations with those obtained in the steel and cement targets described in the first part of this paper shows that the 21-gm jet charge achieves approximately the same penetration in both targets, whereas the bullet penetration into the formation target is only about half that obtained in the neat cement targets. This suggests that penetration of hard formation with bullets may be limited; but, since Berea sandstone is considered only a medium hard formation, its confinement in a small diameter, heavy-walled target cylinder may possibly be a factor in reducing the bullet penetration.

The shot hole made by each of the guns used in these tests was filled with a plug which was not removed by backflowing, as illustrated in Fig. 6. The plug formed in the bullet perforation is relatively hard and dense, and consists principally of sand and mud solids. The plugs in the jet perforations also contain sand and mud solids, but, in addition, include a relatively large quantity of debris from the shaped charges.

When the 21-gm charge is used, this shaped charge debris makes up the bottom portion of an extremely hard, dense plug. With the 29-gm experimental charge, both the charge debris and mud solids are unevenly dispersed throughout a comparatively soft, sand plug. It appears that this distribution of the solids with the experimental charge may be a result of the large diameter perforation or possibly, the distribution of forces in and around the jet stream during the perforating operation.

Around the shot hole, which is filled by the plugs described, is a region of affected formation which appears to be composed of crushed and compacted sand grains held in place by the mud plugs. Microscopic examination does not indicate any glazing or fusing of this unconsolidated sand. Normally, there is little or no cracking of the core in the targets perforated with the jet guns; the bullet gun, however, produces hair-line cracks radiating outward from the bullet. The flow data calculated for each test is shown in Table 1. A summary of this data is as follows:

Gun Employed in Firing Test	Bullet	21-Gm Jet	29-Gm Exp Jet
Number of Tests Averaged	10	9	3
Average Diameter and Depth of Formation Perforation, Inches	½ x 1	¾ x 4¾	½ x 3
Average Flow Rate Index, $\bar{q}_c$, for Clean Hole Drilled to the Same Dimension as Perforation	0.76	1.29	1.04
Average Flow Rate Index, $\bar{q}_p$, for Perforation	0.46	0.45	0.81
Average Reduction in Flow Rate, Per Cent	39	64	22

If the bullet perforator is taken as an example, these indices mean that if the permeability of the formation, viscosity of the fluid, and the pressure differential across the core are such that 1 bbl of fluid per day is produced through the core with both faces open to flow, then 0.76 B/D should be produced through a clean hole with the same dimensions as the perforation. But, because of the plugging, only a 0.46 B/D was produced. This corresponds to a flow rate 39 per cent less than that which should be obtained with no plugging.

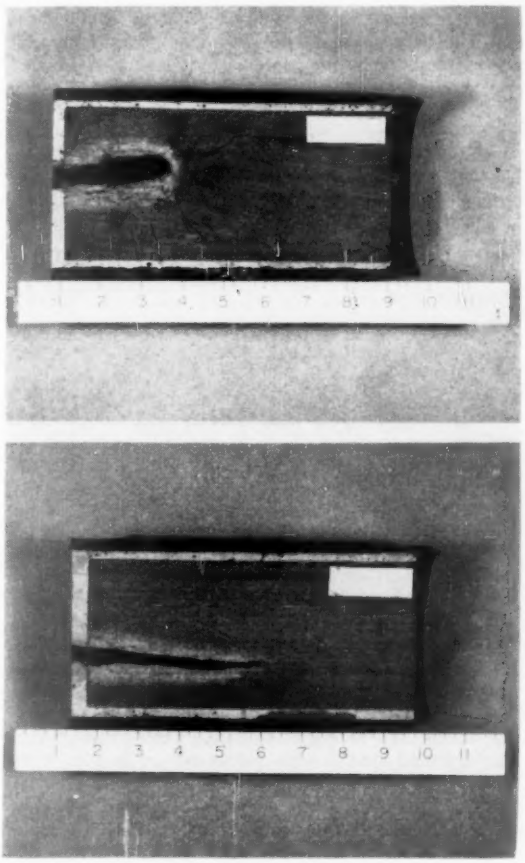

FIG. 6 — EXAMPLES OF FORMATION TARGETS PERFORATED IN THE PRESENCE OF MUD. TOP ILLUSTRATION DEMONSTRATES PERFORATION WITH 4-IN. OD PREMIUM PRICED BULLET GUN; BOTTOM ILLUSTRATION, WITH 4-IN. OD JET GUN WITH 21-GM CHARGE.

Though the jet perforators are penalized by ⅝-in. additional steel and ¼-in. additional Hydromite, the flow rate through the 21-gm jet perforation is approximately the same as that through the bullet perforation. This is indicated by a flow rate index of 0.45 as compared to 0.46. Also, the flow rate through the 29-gm experimental jet perforation is almost twice that achieved by either of the other perforators, as indicated by an index of 0.81. It should be pointed out that if the jets were not penalized by this additional steel and Hydromite, corresponding flow rates would no doubt be greater.

The average restriction per unit depth of penetration is greatest for the 21-gm jet as illustrated by the 64 per cent reduction in flow rate as compared to 39 per cent for the bullet gun and 22 per cent for the 29-gm experimental jet. It should be emphasized that these 29-gm charges are an experimental design not yet commercially available. Tests conducted with these charges have been limited, but the use of a charge design which produces a larger diameter hole appears to provide an approach to reducing the damaging effects of perforation plugging and obtaining greater well productivity.

Since the areal extent of the formation and the radial flow which occurs adjacent to the well is not duplicated in these tests, the percentage reductions in flow rate presented here cannot be directly applied to a well. However, since the pressure drop across a plugged perforation is large compared to the calculated pressure drop from the well bore to a drainage radius of 1,000 ft. for the same volume of flow, viscosity, and permeability, assuming four shots per ft. it appears that the percentage reductions give order of magnitude numbers which may be used in estimating the effectiveness of gun perforating under particular well conditions.

SUMMARY

Penetration

1. Gun perforators are currently available which are capable of providing sufficient penetration for most well perforating jobs, and, in many cases, penetration sufficient to provide productivities equivalent to or greater than open hole, based on previously mentioned analog studies.
2. The bullet perforating process is more adversely affected by heavy casing, hard cement, and hard formation than is the jet perforating process.

Plugging

1. When shooting in mud under conditions similar to those used in these tests, a plug which is not removed by backflowing is formed in the perforation, and the formation surrounding the shot hole is altered so that the flow rate through the perforation is restricted in varying degrees.
2. Total flow was approximately equal through perforations made with the 21-gm jet and with the premium-priced bullet perforator. The restriction per unit of hole depth was greater with the 21-gm jet than with the bullet perforator, however, the greater penetration obtained by the jet perforator resulted in equal flow through both types of perforations. The flow rate through the experimental jet perforation is almost twice that obtained with either of the other perforators. In considering flow rates, it is recognized that in penalizing the jet penetration with additional steel and Hydromite, the flow rates for these guns are also somewhat reduced.
3. One possible step toward increased productivity for perforated completions is the design of shaped charges which will give a larger diameter hole than the 21-gm charge and a deeper penetration than that obtained with the bullet gun. The 29-gm experimental charge used in these tests is a move in that direction; however, it is not yet known whether merely increasing hole size reduces plugging with jets, or whether the plugging effect may be a function of other factors related to charge design.

In addition to the problems recognized at the beginning of these investigations, many related problems have been uncovered which suggest that, in such an important operation as opening up pay horizons either in field development or wildcat operations, a great many more answers are needed than are now available.

The work presented in this paper covers only one phase of the problems associated with the effectiveness of gun perforating. To obtain sufficient information on this problem to satisfy the needs of the industry, extensive testing will be required under the various conditions which may occur in a well.

It is anticipated that additional work will be done by the authors to evalute the effectiveness of gun perforating, but the magnitude of the problem presents a program too lengthy for one company to complete. It is therefore hoped that this paper has not only stimulated interest in the program described, but will also encourage other companies to participate in similar work.

ACKNOWLEDGMENTS

The authors wish to express their appreciation for the cooperation and assistance from all service companies participating in the perforator penetration tests, and especially to Lane-Wells Co. and Welex Jet Services, Inc., for their assistance in connection with the perforator plugging experiment.

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SOME PRACTICAL ASPECTS of GRAVEL PACKING

C. J. RODGERS

GULF OIL CORP.
HOUSTON, TEXAS

T. P. 3741

ABSTRACT

The present day success of gravel packs to prevent or retard the migration of unconsolidated sands into the well bore is due to: (1) the use of a saline or non-aqueous, nonsolids drill fluid, (2) proper preparation of the well bore prior to gravel packing, and (3) pressure placement of the gravel.

The experience gained from the "pressure pack" method of gravel packing indicates that sand-free fluid production can be maintained for a length of time sufficient to make the operation economically attractive. Data pertaining to the first 15 wells so completed by Gulf indicate that for each dollar spent to effect the completion, there will be a return of more than $2.92.

The pressure pack technique of gravel packing is essentially the placing of gravel in and adjacent to the producing formations. This is done with fluid pressure and by the use of a drill fluid that will permit partial or complete loss of returns to the formation during placement. This technique was first intentionally used by Gulf in May, 1950, and since that time has been applied in more than 90 wells.

Other advantages claimed for this type of completion are that the pressure placement of the gravel has a scouring effect on the casing perforations, that additional drainage channels to the well bore are created, and that the possibility of shifting of the formations adjacent to the casing is minimized and possibly prevented.

INTRODUCTION

During the past few years, the use of gravel to prevent or retard the migration of unconsolidated sands into the well bore has met with a favorable degree of success. Numerous methods and techniques of "gravel packing" have been used, each having its own relative merits, and with varying results.

M. L. Cashion[1] in 1939 ably reviewed the history of gravel packing to that time. As stated in his paper, ". . . the idea of gravel packing wells is not new." During the period 1939 to 1949, very little if any progress or change in technique in this type of completion was made. However, it was noted in some cases that during the placement of gravel, if there was a loss of drill fluid to the formation, there was a corresponding loss of gravel to the formation.

Also, it was noted that in those gravel-packed completions (opposite casing perforations) that "sanded up," there was found to be an absence of gravel in the annular space between the liner and casing, although gravel had previously been placed in this space and no gravel had been removed from the well at the surface. These findings resulted in the placement of gravel with fluid pressure and by the use of a drill fluid that would permit partial or complete loss of returns to the formation during placement. Pressure placement of gravel became an accepted practice in late 1949 and early 1950.

Another fact brought to light that has contributed to the current success of gravel pack completions is that drilling fluids containing solids will to some extent cause plugging of the screening medium or blocking of the producing section. The removal of these solids by chemical action, mechanical action, or a combination of the

[1]References given at end of paper.

Manuscript received in the Petroleum Branch office July 29, 1953. Paper presented at the Petroleum Branch Fall Meeting in Dallas, Texas, Oct. 18-23, 1953.

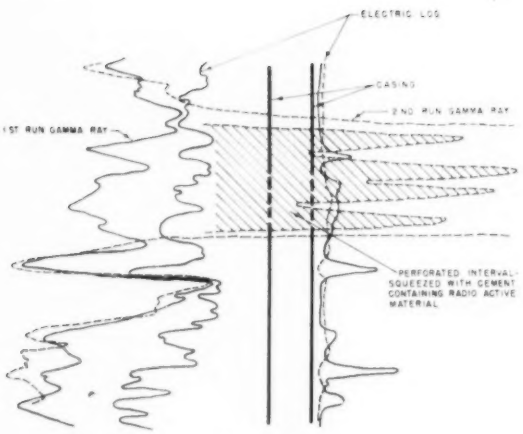
ELECTRIC LOG
CASING
2ND. RUN GAMMA RAY
1ST. RUN GAMMA RAY
PERFORATED INTERVAL SQUEEZED WITH CEMENT CONTAINING RADIO ACTIVE MATERIAL

FIG. 1 — FORMATION PARTING CAUSED BY SQUEEZE CEMENTING.

two means, has been found to be essential for the success of any type of screening medium. The detrimental effects of fresh water or fresh water muds are also recognized and have resulted in their discontinuance in some cases. When fresh water mud is used in the filtrate loss is considerably less than was the case a few years ago.

CURRENT PROCEDURE

The present day success of gravel packing in completion work is believed to be due primarily to: (1) the use of saline or non-aqueous, nonsolids drill fluid (normally salt water that is compatible with the formation fluids or oil), (2) proper preparation of the well bore prior to gravel packing; i.e., the removal of the original drill mud from the well bore and as much as possible from the sand face, and (3) pressure placement of the gravel.

Pressure placement of gravel may result in a parting of the stratified formations within the producing interval along bedding planes or other zones of weakness if sufficient pressure is applied. Fig. 1 illustrates the formation parting that resulted from squeeze cementing perforations in 5 in. OD casing in a well in the Thompsons field, Texas. The interval squeezed is a Frio sand section at a depth of approximately 5,300 ft. A gamma ray survey was conducted before and after squeeze cementing. A total of 173 sacks of cement containing a uniformly distributed radioactive material was forced through the casing perforations at a maximum and final surface gauge pressure of 4,700 psi (a 9.5 lb per gal mud was used as the drill fluid). Comparison of the two gamma ray curves indicates that the greatest increase in radioactivity is confined principally to the section opposite and adjacent to the perforated interval and that the formations within this section are parted as the increased radioactivity varies within this section.

REASONS FOR GRAVEL PACKING

It is reasoned that if the formations are pressure parted and gravel is forced into these induced cracks or fissures, the possibility of their being closed when the applied pressure is released will be eliminated. Also, these openings will provide additional drainage channels to the well bore. This will permit fluids to enter the well bore at lower velocities and, therefore, will tend to minimize the erosional effect of the fluid movement. The mechanical propping of the formations should provide added resistance to any tendency these formations may have to slough or shift, if there is a reduction in bottom hole pressure. The ability of the well to produce may also be improved by this parting and propping of the formations.

Numerous breaks in the exposed formations will be caused as the applied pressure is progressively increased. The breaking down and packing with gravel of these zones of weakness results in the mechanical consolidation of the producing interval, in the individual beds or layers having more strength to shear, and in a greater drainage area being opened to the well bore.

The use of the word "gravel" as pertains to gravel packing may be misleading. The individual grains are of such a size that the aggregate is usually considered to be a coarse sand. The grain size normally used for packing producing wells is 0.040 to 0.060 gauge (15-to-10 mesh) and for packing injection wells 0.060-to-0.090 gauge (10-to-8 mesh). Considerable laboratory work[2,3,4] has been done in order to determine the physical properties this gravel should have, including the sizes as stated above. Actual field testing in the reservoirs encountered in the Gulf Coast has substantiated the findings of the laboratory experiments. This gravel may be purchased from several supply firms and is packaged in sacks of 1 cu ft capacity.

ESSENTIALS FOR SUCCESS

The first well in the Gulf Coast District to be intentionally "pressure packed" by Gulf was a well at Sour Lake, Texas, in May, 1950. Since that time, several things have been found to be essential for the success of the operation. The formation pressure of the interval to be packed, or the differential to be caused by artificial lift equipment, or a combination of the two must be such that a sufficient volume of the drill fluid lost to the formation while gravel packing will be recovered and thus allow the entry of formation fluid to the well bore.

As gravel packing is usually a remedial measure, it has been necessary in most cases to place the gravel through perforations in the casing. These perforations should be of a size and density to prevent a tendency for the gravel to "bridge" opposite these holes inside the casing. In practice, it has been found that there is less tendency of the gravel to bridge when the perforations are 15/32 in. OD or larger and are of a density of at least six holes per foot. The ideal situation would be the complete removal of the casing opposite the producing section; i.e., the interval to be gravel packed. The economics of such an operation with the tools now available is subject to question, however. If the jet- or shaped-charge tools for the removal of a section of casing (now in the process of development and experimentation) are found to be adaptable, this possibility would be considered more favorably.

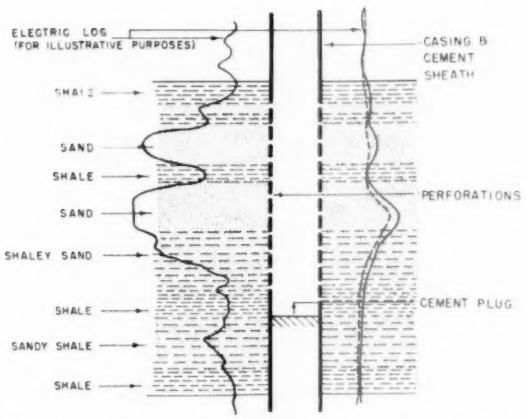

FIG. 2 — SECTION OF WELL BORE AND FORMATION TO BE GRAVEL PACKED.

TECHNIQUE

In order to describe the technique of gravel packing used by Gulf in the Gulf Coast District, sketches have been prepared (Figs. 2, 3, and 4). These sketches are of ideal conditions that may or may not be realized in practice. Fig. 2 illustrates the section of the well bore and formation to be gravel packed. Depicted is a well completion with the casing cemented through and opposite the producing sand body. The well casing and cement sheath have been perforated, allowing for drainage of fluids from the sand into the well bore. In this figure, the plug is near the bottom of the perforated interval. The sand face has been cleansed of foreign materials by swabbing, bailing, or washing. The electric log of this section of the hole has been superimposed on all sketches in order to illustrate the stratification of the sands and shales.

Fig. 3 shows the placing of the gravel. In this phase of the operation, a placement fluid (usually salt water) containing gravel is pumped down the tubing. The gravel is deposited in the well bore. By applying fluid pressures and reciprocating the tubing, gravel is forced through the perforations against the sand face, along bedding planes, and in any fractures that may exist or that may be caused to occur in the formation. The placement fluid is either lost to the sand body or returns to the surface through the annular space between the tubing and casing. During squeezing operations the fluid is lost to the formation. Gravel is placed in this manner until the well bore and formation have been "packed" to the desired fluid pressure. The basic idea involved is to pump gravel into or against the formation until the sand in the formation (reservoir) is mechanically impounded and results in a consolidated sand mass. This minimizes the possibility of sand movement into the bore hole.

BRADENHEAD SQUEEZING

The fluid pressure is applied in a manner that has commonly been referred to as "Bradenhead squeezing." The necessary surface equipment consists of a pack-off around the tubing or drill pipe at the well head (in this case a blowout preventer) that prevents or regulates the discharge of the circulating or placement fluid from the well bore. The squeeze pressure, caused by the circulating pump's attempting to force fluid in the tubing or drill pipe, is exerted on the tubing or drill pipe, the casing, and the formation. The maximum pressures that can be applied in this manner are limited to the bursting strength of the casing. For that reason this method of applying pressure is not applicable to high pressure work. Tools and methods will, no doubt, be designed and developed to remedy this situation. Several service companies claim to have such a tool available for use.

After placement of a quantity of gravel in the well bore to cause a fill-in above the top of the perforated interval, additional gravel is placed in the well bore. This is done so that after the screen liner is positioned (shown in Fig. 4), gravel fills the annular space between the liner and casing.

PLACING THE SCREEN LINER

Fig. 4 shows the screen liner in place with the packer sealed. This assembly has previously been run in on tubing or drill pipe attached to the packer by means of a setting tool. Wash pipe extends from the back pressure valve or set shoe inside the screen liner to the setting tool. This wash pipe permits the screen liner assembly to be washed down through the gravel fill-in in the well bore. In this washing down operation, the circulating fluid is pumped down the tubing or drill pipe, through the setting tool, the wash pipe, and out the set shoe. Then it is allowed to return to the surface through the annular space between the tubing and casing.

When the screen is positioned as desired, the setting tool is released from the packer by rotation. The setting tool assembly is raised a height sufficient to disengage the wash pipe from the set shoe and to allow the setting tool to disengage the packer. The setting tool is then lowered, and weight is applied to the packer to cause collapse and result in a seal to the casing. The

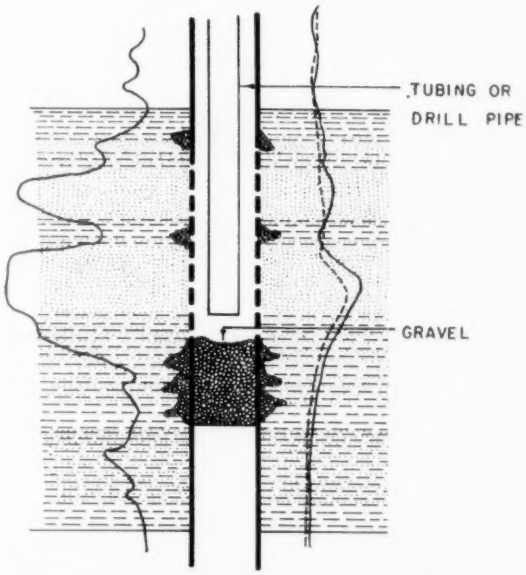

FIG. 3 — PLACING OF GRAVEL DURING THE GRAVEL PACKING OPERATION.

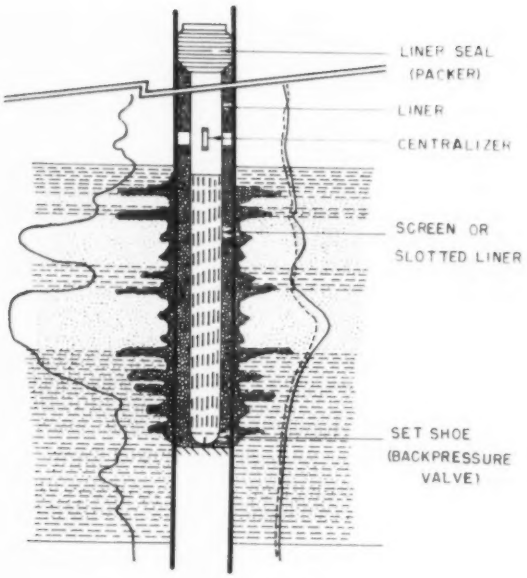

FIG. 4 — SCREEN LINER IN POSITION.

setting tool and wash pipe are pulled from the hole, leaving a gravel packed screen-liner setting as shown in Fig. 4. The customary tubing setting is made for completion.

IMPROVED METHODS

The above technique has been modified and improved and has resulted in the use of a gravel pack strainer assembly shown in Fig. 5. This assembly allows the completed interval, either open hole or perforated casing, to be pressure packed and the strainer setting made in one trip of the pipe. The assembly consists of a nose piece, slotted pipe, liner, setting tool and sleeves, and inserted wash pipe. The nose piece contains a flapper valve that is held in an open position by the wash pipe. Gravel is pumped down the tubing or drill pipe, through the wash pipe, and out the nose piece.

Fluid pressure is then applied and the gravel pack strainer assembly reciprocated by raising and lowering the tubing or drill pipe. These pressures cause the gravel to be pressure packed in and opposite the completed interval. The assembly is then washed into place by normal circulation.

Right-hand rotation of the tubing or drill pipe causes the setting tool to become disengaged from the setting sleeve. The tubing or drill pipe, the setting tool, and wash pipe are then pulled from the hole and the conventional tubing setting made. The flapper valve in the nose piece is allowed to close when the wash pipe is pulled.

CALCULATING MAXIMUM PRESSURE

The maximum pressure used in the placement of the gravel is arrived at by calculating the top hole gauge pressure necessary to exceed slightly the overburden pressure. By overburden pressure is meant "the calculated pressure at any given depth exerted by the theoretical weight of overlying formations as calculated from the average rock density."[5] The general opinion is that the overburden pressure gradient for formations along the Texas-Louisiana Gulf Coast is roughly 1 psi per ft of depth. The maximum desired gravel placement pressure (top hole gauge pressure) is equal to the pressure at the perforated interval (due to the weight of the overlying beds) minus the hydrostatic head of the fluid column plus 100 psi. The gravel pack squeeze pressure as calculated above is intended only as a basing point for present and future experimentation.

During the development or experimental phase of the work that preceded the adoption of the above technique, several innovations were tried. Some wells were packed with such volumes of gravel and at such pressures that it was possible to wash out the gravel inside of the casing before running in the screen-liner. In effect, a gravel pack that was self-supporting was placed adjacent to and in the producing interval. After positioning the screen-liner, the annular space (between the casing and screen-liner) was packed and the well completed in the conventional manner.

This procedure was desirable, as it allowed the completion to be made without disturbing the final pack. It soon became apparent, however, that in order to effect

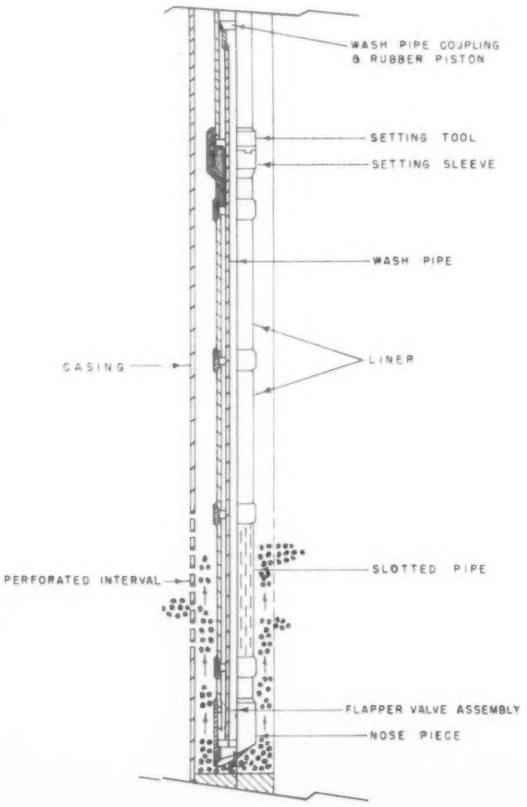

FIG. 5 — GRAVEL PACK STRAINER ASSEMBLY.

the self-supporting pack, it was usually necessary to repeat the squeezing and washing out operations until the gravel outside the casing was so arranged that it did not flow back into the well bore. This was both time consuming and expensive; therefore, on later wells the screen-liner was washed down through the gravel. As the wells produced satisfactorily this method of placement was adopted.

Strainers

Wire-wrapped screen and slotted pipe have been used as strainers. Both have performed satisfactorily. All but five of these settings (more than 90 have been made by Gulf) were made inside of casing opposite perforations. All of these inside strainers were either 2⅜ in. OD or 2⅞ in. OD. The casing size apparently does not limit the maximum size of the strainer that may be used to the degree that, prior to pressure packing, had been advocated; i.e., 2⅞ in. OD strainer inside of 7 in. OD casing, 2⅜ in. OD strainer inside of 5½ in. OD and 5 in. OD casing. Strainers of 2⅞ in. OD have been set inside of 5 in. OD casing opposite perforations of wells which have produced satisfactorily.

Kenneth E. Hill has stated that, "The thickness of gravel should be at least five gravel grain diameters."[5] This requirement is more than satisfied by the placement of a 2⅞ in. OD strainer inside of 5 in. OD casing, if the annular space between these two pipes is filled with 0.040-to-0.060 gauge gravel. However, 2⅜ in. OD strainer inside of 5 in. OD casing will allow an increase in annular volume of approximately 24 per cent more than that afforded by a 2⅞ in. OD strainer inside a 5 in. OD casing.

The reduction in cross sectional area of the strainer may be justified in order to provide more annular volume as a storage space for gravel. As a well is produced and fluid is removed from the reservoir, the gravel stored in the annulus is intended to provide replacement gravel to the pack, if this pack is disturbed by fluid movement or a reduction in bottom-hole pressure. Also, of no little importance is the fact that the 2⅜ in. OD strainer should be easier to "fish out" than a 2⅞ in. OD strainer. The smaller strainer would be more difficult to bail or wash out; however, if either strainer were to become sanded up, more extensive remedial measures probably should be undertaken.

Strainer Gauge Sizes

The gauge size of the strainer should be such that it will not pass the smallest gravel used in packing; e.g., when 0.040-to-0.060 gauge gravel is used, a strainer of gauge size less than 0.040 would be in order. Since allowance should be made for mechanical imperfection in the manufacture of the strainer and also for possible fracturing of the grains of gravel during placement, a 0.020-gauge strainer is normally used.

Table 1[6] is a compilation of several representative gravel pack completions in the Texas Gulf Coast. As will be noted from this datum, the sacks of gravel placed per foot of perforations varied from well to well even within the same field. For the wells listed, the maximum cubic feet of gravel placed per foot of perforations was 8.6, and the minimum was 1.4. The barrels of salt water used for the placement of this gravel varied in a like manner but were not necessarily in proportion to the cubic feet of gravel placed. For example, at one well a total of 8.0 cu ft of gravel was placed for each foot of perforations, and 46.2 bbls of water were required to place each cubic foot of gravel.

At another well, a total of 8.0 cu ft of gravel was also placed per foot of perforated interval, but only 18.0 bbls of water per cubic foot of gravel were required for placement. As shown, a maximum of 46.2 bbls of water was used to place a cubic foot of gravel, and a minimum of 3.6 bbls was used for a like purpose.

Satisfactory Results

The production performance of the wells that Gulf has gravel packed has been very satisfactory. A record of production tests of the first wells completed in this manner is given in Table 2. Before being gravel packed, all of these wells were off production due to being sanded up, or they had not been completed due to the well's inability to produce, which was caused by sanding.

As shown by Table 2, only two of the completions (of the 46 listed) were initial failures: a well at Goose Creek and one at Thompsons. The work at Goose Creek was performed according to the procedure outlined above; however, after it was packed, the well

TABLE 1 — GRAVEL PACK COMPLETION DATA

WELL DESIGNATION	SIZE CSG. OR LINER INS. O. D.	PROD. INTERVAL	FEET PERF.	TOTAL SKS. GRAVEL OUT	SKS. GRAVEL PER FOOT PERF.	WATER USED BBLS.	WATER PER SK. GRAVEL BBLS.	COST DOLLARS	POTENTIAL TEST OIL	METHOD PROD.
A	5 in.	7124-7131 ft.	7	28.5	4.1	411	14.4	2244	52	Pump
B	5½	7040-7064 ft.	24	34	1.4	285	8.8	1975	54	Pump
A	5 in.	4383-4400 ft.	17	51	3.0	1990	39.0	2867	7	Pump
B	5 in.	4875-4884 ft.	9	72	8.0	3331	46.2	3960	43	Pump
C	5½	4246-4273 ft.	27	100	3.7	925	9.3	4743	51.0	Pump
A	5 in.	3321-3350 ft.	29	69	2.4	854	12.4	3529	94	Pump
B	5½	3503-3517 ft.	14	109.5	7.8	393	3.6	5818	79	Pump
C	5½	3458-3490 ft.	32	45	1.4	534	11.9	2200	103	Flow
D	5½	3468-3486 ft.	18	41.5	2.3	1300	31.4	2551	112	Flow
E	5½	3370-3396 ft.	26	120	4.6	2500	20.4	4597	152	Flow
A	5½	2580-2592 ft.	12	103	8.6	2028	19.7	4006	35	Pump
A	5½	5280-5295 ft.	15	68	4.5	900	13.2	4067	88	Pump
B	5½	4494-4498 ft.	4	32	8	575	18.0	2058	56	Flow
C	5½	5442-5500 ft.	58	79	1.4	1555	19.7	4503	99	Pump

NOTE: Cost figures include cost to gravel pack well and run screen. Gravel pack costs include service charges and royalty fees. This does not include pulling old liner or running production string.

failed to produce any fluids. The well did not sand up. At Thompsons, well conditions prevented proper conditioning of the bore hole before packing, and the recoverable oil was believed to be such that large expenditures should not be made to remedy this situation. This well sanded up while being tested after gravel packing.

Two wells, both at Goose Creek, sanded up after having produced substantial volumes of oil. One of the wells produced 7,385 bbls of oil before sanding up and the other produced 6,867 bbls of oil before sanding up.

Another well, also at Goose Creek, sanded up approximately 11 months after being gravel packed and after an attempt was made to increase the rate of production by the injection of chemicals into the producing section. In this case, it is believed that the pack around the screen or casing was ruptured when an attempt was made to squeeze out the chemicals.

Histories of Gravel Packed Wells

Very little repair work to gravel pack completions has been necessary. At a Sour Lake well, the daily producing rate declined from the initial completion of 35 bbls of oil and 36 bbls of salt water to 6 bbls of oil and 25 bbls of salt water in an 11-month period, or after the well had produced approximately 4,543 bbls of oil. After the producing section was acidized with 450 gals. of inhibited hydrochloric acid, the daily produced volumes increased to 8 bbls of oil and 43 bbls of salt water, an increase of 20 bbls of fluid per day. This rate declined, however, and as shown by the last test made two months after having been acidized, the well was producing at a daily rate of 5 bbls of oil and 30 bbls of salt water.

The producing rate of a well at Goose Creek declined in 10 months time from 29 bbls of oil and zero barrels of salt water per day after it was gravel packed to 1 bbl of oil and zero bbls of salt water per day. It had produced 3,632 bbls of oil. The producing section was squeezed with a chemical mixture. After considerable difficulty was encountered over a two-week period while attempts were made to produce the well, it sanded up. The well bore was bailed clean, and after the fluid was pumped out of the casing, the well produced small volumes of dry gas. It was assumed that this section was depleted of oil, and the well was plugged back and completed in a higher sand.

REPACKING

Several repacking jobs have been performed and the over-all results from a production standpoint have been erratic. In some of these instances meager reservoir information was available, and when the rate of production declined, it was assumed that the original pack had

TABLE II — WELL PERFORMANCE — GRAVEL PACK COMPLETION

FIELD	WELL DESIGNATION	PERFORATED INTERVALS	TESTS				
			AFTER GRAVEL PACKING		LAST TEST		CUMULATIVE OIL
Anahuac	B	7040-7064 ft	54 oil	17 water	5 oil	9 water	10,861
	A	7124-7131 ft	52 oil	78 water	17 oil	66 water	7,582
Big Creek	A	4074-4090 ft	57 oil	2 water	3 oil	0 water	11,084
	B	3970-3980 ft	20 oil	12 water	0 oil	4 water	4,559
			Plugged Back				
	C	4258-4268 ft	30 oil	10 water	21 oil	20 water	18,947
Fannett	A	5280-5295 ft	88 oil	15 water	12 oil	50 water	8,966
	B	4494-4498 ft	56 oil	1 water	21 oil	2 water	13,202
			C.I., High Input Ratio, Plugged Back				
	C	2318-2330 ft	91 oil	18 water	85 oil	77 water	12,869
	D	5482-5500 ft	99 oil	85 water	121 oil	60 water	51,980
Goose Creek	A	3234-3246 ft	94 oil	17 water	62 oil	93 water	65,386
	B	4100-4110 ft	2 oil	16 water	7 oil	0 water	3,734
	C	2184-2198 ft	Plugged Back, Did Not Produce Commercially				
	D	3074-3106 ft	106 oil	35 water			7,385
			Plugged Back				
	E	4423-4429 ft	79 oil	60 water	91 oil	97 water	36,012
	F	4237-4242 ft	68 oil	0 water	7 oil	6 water	7,753
			Regravel Packed; Unsuccessful, Plugged Back				
	G	3402-3412 ft	82 oil	123 water	8 oil	104 water	14,865
	H	4168-4182 ft	29 oil	0 water	1 oil	0 water	3,632
			Plugged Back				
	I	4323-4327 ft	125 oil	14 water	7 oil	370 water	6,571
	J	4360-4376 ft	14 oil	2 water	12 oil	0 water	13,781
	K	3366-3374 ft	76 oil	250 water	23 oil	163 water	23,276
	L	4221-4228 ft	13 oil	4 water	6 oil	0 water	2,112
	(Sold)						
Hankamer	D	3882-3898 ft	21 oil	65 water	18 oil	71 water	11,054
	B	4875-4848 ft	54 oil	162 water	43 oil	231 water	28,573
	E	4465-4473 ft	10 oil	19 water	9 oil	0 water	5,976
	F	4651-4667 ft	28 oil	23 water	8 oil	12 water	8,830
	G	3927-3938 ft	23 oil	91 water	16 oil	7 water	11,224
	A	4383-4400 ft	7 oil	20 water	10 oil	39 water	8,075
	C	4246-4273 ft	51 oil	52 water	46 oil	57 water	38,028
Pierce Junction	A	3934-3938 ft	88 oil	131 water	10 oil	200 water	5,016
	B	4010-4014 ft	66 oil	28 water	7 oil	2 water	11,113
	C	5210-5218 ft	94 oil	50 water	28 oil	23 water	31,861
South Liberty	B	3503-3517 ft	79 oil	20 water	2 oil	104 water	10,729
			Plugged and Abandoned				
	C	3458-3490 ft	103 oil	0 water	108 oil	0 water	57,049
	D	3468-3486 ft	112 oil	21 water	61 oil	113 water	47,582
	E	3370-3376 ft	121 oil	30 water	109 oil	0 water	50,140
	F	3318-3350 ft	101 oil	4 water	105 oil	0 water	45,158
	G	3450-3476 ft	103 oil	5 water	10 oil	23 water	14,100
Sour Lake	A	2580-2592 ft	35 oil	36 water	5 oil	30 water	6,459
			Plugged and Abandoned				
South Thompson	A	5370-5375 ft	120 oil	0 water	54 oil	109 water	34,658
	B	5364-5374 ft	37 oil	109 water	8 oil	75 water	10,684
Thompson	A	5315-5321 ft	115 oil	115 water	33 oil	0 water	9,807
	B	5260-5280 ft	13 oil	4 water	8 oil	1 water	10,178
	C	Unsuccessful	Plugged and Abandoned				
	D	5234-5255 ft	64 oil	28 water	54 oil	16 water	49,999
		5283-5299 ft					
	E	5312-5359 ft	109 oil	42 water	46 oil	125 water	51,052
West Bay	A	8999-9011 ft	283 oil	0 water	15 oil	0.5 water	2,617
			Plugged Back				

become plugged. Yet after repacking, in several cases the producing rate was not improved. It is now believed that these intervals were at or near depletion before the repacking work was performed. Repacking has been successfully applied in those wells that became sanded up either from erosion, corrosion of the setting, or shifting of the gravel pack after large fluid withdrawals.

The examples cited above illustrate the types of remedial measures attempted to date by Gulf on the initial gravel pack completion. It is probable that more work of this nature will be necessary in the future. In those cases where it is evident that the pack has become plugged, temporary relief may be obtained by the use of hydrofluoric acid or a combination of hydrofluoric acid and a surface tension reducing agent. It may be necessary to pull the inside screen and liner, bail the well in order to remove the plugging material, and re-gravel pack for completion.

Improvements Expected

In those cases where the wells have produced large volumes of fluids and there has been a drop in bottom-hole pressure that will permit shifting of the formation, it may be that such wells should be gravel packed again. This is also true where fluid movement has caused some shifting, and thereby caused damage to the gravel pack which permitted the well bore to become sanded up.

The mechanics of gravel pack completions are no doubt subject to numerous improvements. At the present time, the cost of this work, as shown by the data of Table 1[6], prohibits its application in known marginal wells. The gravel pack screen assembly was designed and developed to reduce this cost and has resulted in the elimination of one trip of the tubing or drill pipe and the cost of the liner packer. It is hoped that the completion cost can be reduced even more.

Pressure Packing

The experience gained from field applications of the pressure pack technique of gravel packing indicates that sand free, fluid production can be maintained for a length of time sufficient to make the operation economically attractive. Other advantages claimed, secondary in nature and difficult to verify, are that the pressure placement of the gravel has a scouring effect on the casing perforations, that additional drainage channels to the well bore are created, and that the possibility of shifting of the formations adjacent to the casing is minimized and possibly prevented.

The disadvantages of this technique are that large volumes of placement fluid are lost to the formation, and the gravel squeeze pressures may rupture the casing or break down the cement seal around the casing above or below the producing interval. In practice, it has been necessary in a few cases for the applied gravel squeeze pressure to be less than the desired maximum due to the estimated low bursting strength of the casing. There are no known instances in wells gravel packed by Gulf where the casing has been ruptured or the cement around the casing damaged because of the applied gravel squeeze pressures. The loss of placement fluid to the formation is a necessary evil for this type of completion and has not proved to be of a serious nature.

MONETARY VALUE

In order to place a monetary value on this type of completion, the following data pertaining to 15 of the first wells so completed by Gulf have been assembled.

Total cost to recomplete $143,841

This is the total job cost and includes all services and materials necessary to prepare the wells for packing; such as, pulling old screens, reperforating, cleaning out, gravel pack service charges, royalty fees, etc., in addition to the rig time costs actually required to gravel pack and restore the wells to a producing status.

Accumulated production resulting from these recompletions — oil 224,060 bbls.

The first of these wells was restored to production Oct. 10, 1950, the last Aug. 27, 1951, and the total barrels of oil produced since recompletion to May 1, 1953, is as shown above.

Daily production upon recompletion — oil 664 bbls

Present daily production — oil 214 bbls

Of the 15 wells selected for this compilation, eight are producing at this time, two were initial failures. Two wells have been abandoned, one has been plugged back, one was sold, and one well is now off production awaiting plug back operations.

The expenditure of $143,841 has made possible recovery of 224,060 bbls of oil to May 1, 1953, or a return of $2.92 for each dollar spent. Normal operating expenses have been deducted from the return figure stated above. Attention is brought to the fact that in some of these wells the gravel pack completion was made only after all other known sand control measures had failed. As eight of these wells are still producing, the ratio of return of $2.92 per dollar expended will increase with time.

ACKNOWLEDGEMENT

The author wishes to express his appreciation to the Gulf Oil Corp. for the release of the data contained in this paper.

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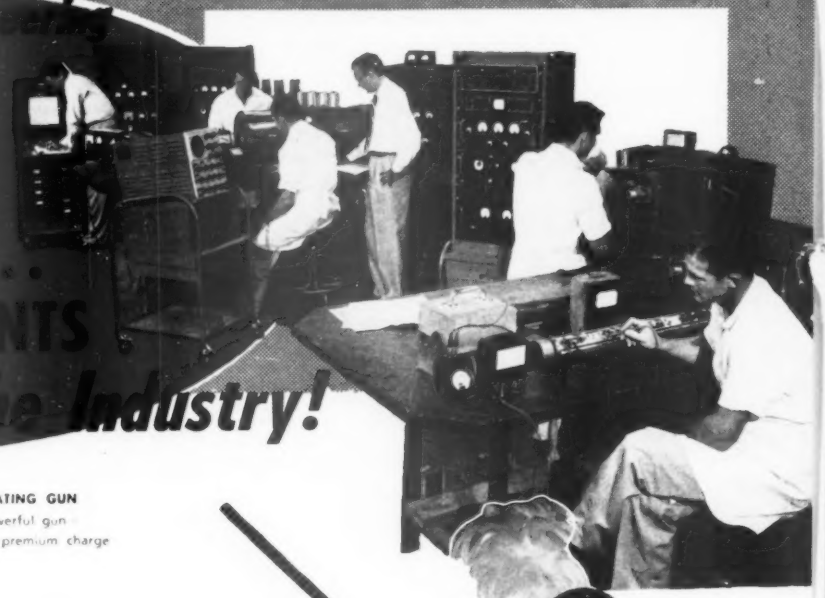

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PERSONALS

TOM E. MORTON has been transferred from Dallas to Houston, where he will

serve as assistant division manager and division engineer for Halliburton Oil Well Cementing Co. Morton, a graduate of the University of Oklahoma, joined Halliburton in 1941. After a tour of duty as a Corps of Engineers officer, he rejoined Halliburton and worked in various parts of Texas and Oklahoma before moving to Dallas in 1950. He was secretary-treasurer of the Dallas AIME section in 1953, and a member of the Petroleum Branch Admissions Committee.

★

FRANK S. MILLARD is now a petroleum technologist in the Geological Department of The Carter Oil Co., Tulsa. He was formerly associated with Schlumberger Well Surveying Corp. in Midland.

★

A MORAZZANI is now in charge of the Rocky Mountain area of the Schlumberger Well Surveying Corp., with headquarters in Denver. He replaced PAUL D. CHABAS, area manager since 1950. Morazzani, a native of France, studied engineering at Ecole des Arts & Metiers of Paris. After joining the corporation in 1937, he worked in Louisiana, Texas, and Illinois. In 1951 he became manager of the Northeast area, with offices in Evansville, Ind.

★

DEE F. PENDLEY, JR., is now assistant division engineer for the Magnolia Petroleum Co. at Oklahoma City. He was formerly district engineer for Magnolia at Electra, Texas.

JAMES R. UNDERWOOD, JR., has been assigned engineer in the Gulf Coast Division of Sohio Petroleum Co., Houston. He recently was released to inactive duty by the Navy. While in the Navy, Underwood served as navy representative on the Joint Staff of the Petroleum Office in Korea and then in the same capacity he was transferred to the headquarters staff of the Korean Communications Zone. His last assignment was on the staff of Commander Service Forces, Pacific, as the assistant technical and engineering officer in the Pacific Command Petroleum Office, Pearl Harbor.

★

A. B. CROWTHER, JR., is now taking advanced studies at the University of Texas through a fellowship granted under the Lane-Wells Scholastic Program. The program is "designed to aid promising students and graduates to continue their studies and research in petroleum engineering." A native of San Antonio and a graduate of Texas A&M, he plans to specialize in exploitation engineering.

★

J. ED WARREN is a new vice-president of The National City Bank of New York, and is now in charge of petroleum business. He was formerly Deputy Petroleum Administrator for Defense and is a past president of the Independent Petroleum Association of America and of the American Association of Oil Well Drilling Contractors.

★

RICHARD L. BORGAN, engineering trainee, has been transferred to Chase, Kansas, from Verona, Pa. He is with the Gulf Oil Corp.

M. M. FIDLAR became vice-president in charge of exploration of Mountain Fuel Supply Co., Salt Lake City, on Jan. 1. He was assistant state geologist and state gas supervisor for the Indiana Department of Conservation from 1936 to 1938, then was Indiana district geologist for the Ohio Oil Co. for the next five years. In 1942 he received his PhD in geology from Indiana University. In 1943 Fidlar joined Mountain Fuel Supply Co and established residence in Rock Springs, Wyo., his present home.

★

PAUL D. CHABAS has become manager of headquarters services in the Schlumberger Well Surveying Corporation's offices at Houston. He is a graduate of Ecole Superiure de Electricite' of Paris. Joining Schlumberger in 1934, he set up the first office in West Texas at Midland. After working in Louisiana and Wyoming, he became assistant manager of the Rocky Mountain area in 1948, then advanced to area manager.

★

GENE J. KAEFER is now in Houston, Texas, with Shell Oil Co. as exploitation engineer. He was formerly located in Hamilton, Ohio.

★

W. F. WEST has become director of engineering, geological, and exploration activities of the J. B. Stoddard organization, independent oil producers of Dallas. He is a native of Houston and attended the University of Texas and Stanford University, where he receive his MS degree in petroleum engineering in 1948.

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PIRSON SPEAKS AT FORT WORTH

Dr. Sylvain J. Pirson, Stanolind Oil and Gas Co., Tulsa, was scheduled to present a talk entitled "A Universal Theory of Oilfield Performance" at the January meeting of the Fort Worth Local Section. His talk was to cover and enlarge upon ideas he has developed in reservoir behavior since writing his latest book, "Elements of Reservoir Engineering."

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Tulsa — Ahalt, Gordon F. (R, C/S-S-J); Baker, Philip D. (M); Dunn, Thomas Henry (M); Houser, Carl Marshal (J).

PENNSYLVANIA
Bradford — Brewster, Frank McCain, Jr. (M).

TEXAS
Abilene — Baker, Dale Bryan (J); Black, Charles Vernon (A); Carroll, Alton Jackson (C/S-J-M); Coleman, Wilbur Ralph (M); Davis, William Warren (M); Mossholder, Max Vernon (A); Neely, Lemon Grey (M); Riddel, T. Benton (A); Rothwell, Charles, Jr. (M); Taylor, James B. (J); Tilton, Rollin Jack (R, M); Thompson, Robert William (M).
Alice — French, Lewis L. (J); Wilson, William Ward (M).
Beaumont — Koehler, Buford R. (M).
Beeville — Trostel, Norris Howard (J).
Bellaire — Krch, Milford Fred (J).
Brownfield — Bogert, William Max (J); Darby, Embree Lee (R, C/S-S-J); Shaw, Harrold Edwin (J); Swenson, Stanley Dean (J).
Bryan — Crawford, Paul Berlowitz (M).
Coleman — Cheney, Monroe George, Jr. (M).
Corpus Christi — Backer, B. A. (A); Bergman, Herbert Alfred (M); Murchison, George T. (M); Phillips, Ned H. (M).
Dallas — Garrett, John E., Jr. (J); Hinchliffe, William Estes (M); Howson, Frank E., Jr. (M); Leeman, Sam Prescott (C/S-J-M); Penner, Robert Francis (M); Roberts, Thomas Gemmer (J).
Electra — Harper, Harry Eugene (A); Kihneman, Milton Joseph (A); Porter, Will Barnhill (J).
El Paso — Dillon, Robert Emmett (J).
Fort Worth — Barber, John Burton (C/S-J-M); Monaghan, Robert Lee (J); Reynolds, Fred Samuel (C/S-J-M).
Gladewater — Frazier, Marvin Deverle (J).
Hawkins — Wright, John William (R, J).
Henderson — Cox, Loren Charles (J).
Houston — Allen, Gilbert Gordon (J); Blackburn, Charles Lee (J); Casey, John Morgan, Jr. (R, C/S-S-J); Crowder, Jeral Jo (C/S-J-M); Matthews, Charles Sedwick (C/S-J-M); Robertson, Lake, Jr. (C/S-J-M); Stoker, Howell Raymond (A).
Kilgore — Frisius, Edward Nathaniel (M); Land, Jasper Minnis (M).
Longview — Seward, Douglas Crockett, Jr. (J); Tallant, James Luther, Jr. (A).
Lubbock — Lemon, Richard Frank (J); McPeters, Kenneth Dale (J).
Midland — Cummings, Vernon Meldridge (M); Hahn, Walter Leroy (R, C/S-S-J); Sindel, Albert T., Jr. (C/S-J-M).
Odessa — Carpenter, Albert Lewis (C/S-A-M); Donnelly, Richard (J).
Post — Wall, Earl Edward (J).
San Antonio — Donzis, Jerome Milton (C/S-J-M).
Sundown — Boren, Robert James (J).
Thornton — Nance, Charles Wayne (R, C/S-S-J).
Tyler — Johnston, Robert Newton (M); Swan, Wilson Briscoe (J).
Victoria — Dunlap, Cleo Collin (R, C/S-S-J).
Wichita Falls — Durossette, Cecil Richard (J); Hill, Rodney Merle (J), Markolf, Jean Bernard (M); Price, William Kenneth (J); Rathman, Raymond Floyd (J).

WYOMING
Casper — Brown, George Gary (R, C/S-S-J); Burback, Fraser Merritt (C/S-J-M).
Cody — Mathews, Lee Morris (R, C/S-S-J).

CANADA
Calgary — Corey, Berton Hatfield (M).
Stettler — King, John G. (J). ★ ★ ★

Sage to Receive Award At Annual AIME Meeting

One of the presentations to be made in February at the Annual AIME Meeting in New York is the awarding of the ANTHONY F. LUCAS MEDAL to Bruce H. Sage, associate professor of chemical engineering at the California Institute of Technology.

His citation reads: "for his distinguished achievements in research on the phase behavior and thermodynamics of petroleum hydrocarbons; for the development of ingenious techniques and equipment; for the study of these materials under petroleum reservoir conditions; for the resourceful application of mathematics in extending the range of prediction of the behavior of hydrocarbons over a wide range of pressure and temperature; and for his marked contribution to the present-day concepts of good petroleum engineering practice."

USC Chapter Plans for 1954

Several field trips and a Spring Meeting are planned in addition to the regular monthly meetings in 1954 by the University of Southern California Chapter of AIME. Officers for the 1953-54 school year are: Richard Butler, president; Richard E. Collar, vice-president; Fred P. Foy, corresponding secretary; Robert P. Boyle, recording secretary; and Carrol M. Blyth, treasurer.

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Employment

The JOURNAL will post notices of men and jobs available. Companies and AIME members are invited to use this space, for which there is no charge. Except as noted below, address replies to: Code (appropriate number.) JOURNAL OF PETROLEUM TECHNOLOGY, 800 Fidelity Union Bldg., Dallas 1. Show return address on envelope. These replies will be forwarded unopened and no fees are involved.

Replies to positions and personnel listings coded P-7, P-8, P-9, and C1475 below should be addressed to: Engineering Societies Personnel Service, 8 West 40th St., New York 18, N. Y. The ESPS, on whose behalf these notices are published here, collects a fee from applicants actually placed.

PERSONNEL

♦Petroleum engineer, 33, married, BS in petroleum engineering Texas A & M, 9½ years production, drilling, gas, and geological experience. Presently employed. Desire position with responsibility and opportunity for advancement. Code 203.

♦Petroleum engineer, 31, married, one child. Bachelor degrees in petroleum engineering and geology. Five and one-half years major company experience in drilling, production, subsurface geology and reservoir engineering. Desires job with independent or consultant involving subsurface geology, reservoir engineering, or both. Code 206.

♦Geologist, M.S. Experienced petrographer and seismograph interpreter. Six years geophysical work in interpretation of Gulf Coast structures. Graduate training in North American stratigraphy. Petroleum geology, mineralogy and petrology. Desires employment as subsurface petroleum geologist. P-8.

♦Petroleum Geologist. Two years field geologist petroleum explorations, Colombia, S.A. Twenty months subsurface geologist drilling explorations, field development work, completion engineering practices in Mexico. Age 30, married, 3 languages. Seek new connection, foreign or domestic. Presently employed. P-9.

♦Geologist, 35, married, M.S. in geology. Nine years experience exploration and development in metal and non-metallic mining operations in West. Desires shift to petroleum industry for position primarily in office. Available immediately. Pacific Coast or Southwest. P-7.

POSITIONS

♦General Manager — Pipeline, 40-55. Must have had ten years experience in executive capacity for operating an oil pipeline. Will act as general manager and top operating engineer for small products pipeline. 30 per cent traveling. Salary, $15,000 per year. Employer will pay fee. Location, Wyoming. C1475.

♦Chief Engineer—To be in charge of all engineering work for well surveying company. Should be experienced in oil tool design and have knowledge of service company operations. Pay in accordance with extent of experience. Code 558.

HAVE YOU CHANGED YOUR ADDRESS?

In order that publications and correspondence may reach you promptly, the Petroleum Branch, AIME, should be advised as soon as possible of any change in your address, *preferably a month before the change becomes effective.* For the AIME directory and for the Personals column of the JOURNAL OF PETROLEUM TECHNOLOGY, additional information is desired. The form below is provided for your convenience, and should be sent to Petroleum Branch, AIME, 800 Fidelity Union Bldg., Dallas 1, Tex.

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for
Publications _____

Title or Position Held_____

Address for _____
Directory
Listing _____

List below your former title or company position, nature of your new position, or other information of interest to your associates for publication in the JOURNAL OF PETROLEUM TECHNOLOGY.

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Six New Petroleum Local Sections Founded in 1953

By JOE B. ALFORD

A solid foundation for the future growth and development of the Petroleum Branch has been laid during the past two years with the formation of ten new AIME Local Sections that are predominately petroleum in membership. Four of these were organized in 1952 and six in 1953, making a total of 19 AIME Local Sections and two Petroleum Branch Chapters that now serve the Petroleum Branch membership on a local basis.

These local organizations have been formed in response to demand from the rapidly expanding membership of the Petroleum Branch, and in keeping with a policy of the Branch Executive Committee adopted in 1952 that one of the best ways for the Branch to serve its members is to make the organization available to them on a local basis where possible.

This expansion of local sections, and the resulting increase in local AIME activities in the areas concerned, has been a major factor in a similarly rapid increase in Petroleum Branch membership. New Petroleum Branch members, excluding changes of status and student associates, for the past three years have been:

1951 — 344
1952 — 510
1953 — 691

The professional membership of the Branch, excluding students, in August, 1950 was 3,616. On December 20, 1953, it stood at 4,944, an increase of 37 per cent in two and one half years. Many factors have contributed to this healthy growth, but doubling the number of Petroleum Branch Local Sections during the period has undoubtedly been one of them.

Dallas Local Section and North Texas Local Section

First of the new groups to be launched in 1953 was the Dallas Section, which was formed in March. The old North Texas Section contained the Dallas, Fort Worth, and Wichita Falls areas. The Fort Worth area was withdrawn in late 1952, with the formation of the local section, leaving the other two areas in the North Texas section, although somewhat isolated. It was determined that approximately 50 AIME members resided in the Wichita Falls area, and these members were polled to determine their wishes on the formation of a new section. Forty-eight per cent voted for a new section, and an organizational meeting was held in January, 1953.

It was decided that the best procedure would be for the membership in Dallas to petition for a new section, which would leave the North Texas Section primarily concerned with the Wichita Falls area. This plan was approved by Dallas members, who submitted a petition for formation of the Dallas Local Section. The section area encompassed Collin, Dallas, Cook, Denton, Rockwall and Grayson counties. This left the following 12 counties in the North Texas Section area: Archer, Baylor, Clay, Foard, Hardeman, King, Knox, Montague, Throckmorton, Wichita, Wilbarger and Young.

Dallas Local Section officers that were instrumental in formation of the new Section, and which served the section during the remainder of the year were: E. R. Brownscombe, Atlantic, chairman; R. T. Bright, Mercantile Bank, vice-chairman; and Tom E. Morton, Halliburton, secretary-treasurer.

Officers elected in March, which served the North Texas Section in Wichita Falls for the balance of the year were: Rollie P. Dobyns, Bureau of Mines, chairman; E. N. Durham, Shell, vice-chairman; John H. Bolstad, Continental, secretary; and J. W. Winfrey, Humble, treasurer. The wisdom of establishing a local section in Wichita Falls is shown by the fact that the section secured 28 new members from Mar. 1 - Dec. 31, 1953, for the percentage increase of 54 per cent.

Mississippi Local Section

Petroleum Branch membership in the state of Mississippi was organized into a sub-section of the Delta Section in 1948. Although there has been only about 35 AIME members in the state, they have been quite active in the Mississippi-Sub-Section since its founding, and have held meetings regularly. Interest in the possibility of elevating the group to local section status increased, and the prospects were discussed by the Branch Secretary at a meeting of the group in May. The majority of members favored the action, and a petition was later presented for the formation of a local section to cover the entire state of Mississippi. Agreement on boundaries was secured from adjoining sections, and the petition was approved by the AIME Board of Directors in September. Officers which served the group throughout the year were: John A. Rodgers, Gulf, Baxterville, chairman; David C. Harrell, Sun, Jackson, vice-chairman; Wilson I. Sanderson, Halliburton, Natchez, vice-chairman; and Paul Tsimortos, Gulf, Baxterville, secretary-treasurer.

Denver Petroleum Section and Billings Petroleum Section

Prior to this year, the AIME by-laws have permitted the formation of only one local section in a given geographic area. In several areas of the country where members of different Branch interests were concentrated, the formation of sub-sections to serve them was required. This is considered unsatisfactory from some standpoints, and in response to a request from the Petroleum Branch, the AIME Board removed the restriction to only one section in a given area (See news item in this issue). This opened the way for sections to "overlay" each other, and be formed along professional lines in addition to the geographic area.

The problem of professional organization was particularly important in the state of Colorado, in which some 500 AIME members reside, 78 of them being petroleum members. Although the Colorado Local Section has three sub-sections, a local organization to serve the petroleum members has never been formed. In response to requests from members in Denver, an organizational

meeting was held with petroleum members there on June 23, and the prospects were discussed by the Branch Secretary.

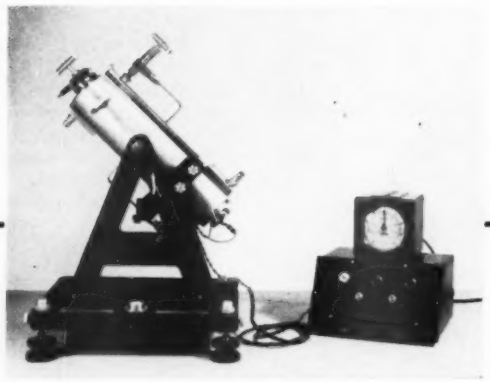
A local organization, the Petroleum Engineer's Club of Denver, had been in existence for some time, and some thought that there was not a sufficient potential in the area to support both this club and an AIME local section. A steering committee was appointed at the June meeting to determine the wishes of petroleum engineers in Denver on forming an AIME section. This action was approved by a considerable majority of the members of the Denver Petroleum Engineer's Club in September, and another meeting of AIME members was held on November 2 for the development of a petition for a section. Because of its co-existence with the Colorado Local Section, it was decided to call the new group the Denver Petroleum Section, although it encompassed the entire state of Colorado. The petition was approved by the AIME Board in November, and the first meeting of the new petroleum section was held on December 2. Officers elected to serve the balance of this year and during 1954 are: T. O. H. Mattson, Texas Co., chairman; R. L. Hoss, Midwest Oil Co., vice-chairman; J. D. Harris, Core Labs, vice-chairman; and R. W. Sneed, Eastman, secretary-treasurer.

With the rapid development of the oil industry in the Rocky Mountains, Billings, Mont., has secured a concentration of Petroleum Branch members. An organization meeting for the formation of a local section there was held by the Branch Secretary on October 27. The meeting was attended by 42 persons, and a great deal of interest in a section and AIME activities was manifested. The group submitted a petition for a section covering the entire state of Montana, and again because of its co-existence with the Montana Local Section, it was decided to call the group the Billings Petroleum Section. Its first formal meeting was held on November 17, and the following officers elected to serve the group for the ensuing year: Howard R. Lowe, consultant, chairman; Charles F. Hunkins, Northern Pacific Oil, vice-chairman; R. L. Dickson, Dowell, vice-chairman; and John G. Yapuncich, Yapuncich-Sanderson Labs, secretary-treasurer.

San Joaquin Valley Local Section

Approximately 75 petroleum members in the San Joaquin Valley of California have been organized during the past few years as a subsidiary group of the Pacific Petroleum Chapter. Since the membership there is in sufficient strength to warrant the formation of a section, an organizational meeting was held with the officers of the group in February. A poll was later conducted to determine the wishes of members on the formation of a section, which voted for such action by a considerable majority. A petition was submitted during late 1953 for the formation of a section, but because of some pending questions on section boundaries it has not yet been approved by the AIME Board. Approval is anticipated in the near future. Harry D. Campbell, Franco Western Oil Co., Bakersfield, is president, and C. A. Davis, Ritchfield, Bakersfield, is secretary-treasurer.

Several additional possibilities for new local sections in the Petroleum Branch still exist, and it is planned that new sections will be formed in these areas in the next year or so. The Branch Executive Committee feels that this is a sound policy that will result in increased service to the membership.



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Casper, Wyo.—Glendive, Mont.—Sterling, Colo.
Calgary and Edmonton, Alberta, Canada
Regina, Saskatchewan, Canada

Schedule of Local Section Meetings

BILLINGS PETROLEUM SECTION: Meets in Billings, Mont. CHAIMAN, H. R. LOWE, Wallace & Lowe, Inc., Billings. SECRETARY, J. G. Yapuncich, Yapuncich-Sanderson Lab., Billings.

DALLAS SECTION: Meets third Monday each month in Dallas. CHAIRMAN, G. R. Brainard, Jr., Lucerne Corp., Dallas. SECRETARY, A. B. Dyes, Atlantic Refining Co., Dallas.

DELTA SECTION: Meets second Tuesday each month in New Orleans. CHAIRMAN, A. L. Vitter, California Co., New Orleans. SECRETARY, B. L. Francis, Texas Co., New Orleans.

DENVER PETROLEUM SECTION: CHAIRMAN, T. O. H. Mattson, Box 2100, Denver. SECRETARY, A. J. Carter, Jr., Bay Petroleum Corp., Denver.

EAST TEXAS SECTION: Meets second Tuesday each month at Gregg County Airport. CHAIRMAN, G. L. Scheirman, Shell Oil Co., Kilgore. SECRETARY, T. A. Banta, Lufkin Foundry & Machine Co., Kilgore.

FORT WORTH SECTION: Meets third Tuesday each month in Fort Worth. CHAIRMAN, M. I. Taylor, Gulf Oil Co., Fort Worth. SECRETARY, T. M. Curtis, Stanolind Oil & Gas Co., Fort Worth.

GULF COAST SECTION: Meets third Tuesday each month in Houston. CHAIRMAN, K. B. Ford, J. R. Butler & Co., Houston. SECRETARY, Pete Cawthon, Jr., City National Bank, Houston.

ILLINOIS BASIN CHAPTER: Meets first Thursday each month in Salem, Ill. (No meetings in July & August.) CHAIRMAN, Jerry Vaughan, Sun Oil Co., Evansville, Ind. SECRETARY, Harry Bridges, Shell Oil Co., Centralia, Ill.

KANSAS SECTION: Meets second Wednesday in Wichita and fourth Thursday in Great Bend. (No meetings in June, July, & August.) CHAIRMAN, J. R. Puckett, Magnolia Petroleum Co., Wichita, Kan. SECRETARY, John T. Gary, Continental Oil Co., Wichita.

LOU-ARK SECTION: Meets third Monday each month in Shreveport, La., CHAIRMAN, C. R. Olson, Ohio Oil Co., Shreveport. SECRETARY, E. P. Ogier, W. C. Spooner, Inc., Shreveport.

MID-CONTINENT SECTION: Meets second Monday each month in Tulsa: study group meets fourth Tuesday each month. (Luncheon meetings each Thursday. Mayo Hotel.) CHAIRMAN, G. C. MacDonald, Gulf Oil Corp., Tulsa. SECRETARY, F. H. Callaway, Stanolind Oil & Gas Co., Tulsa.

NORTH TEXAS SECTION: Meets second Monday each month in Wichita Falls. CHAIRMAN, D. B. Meisenheimer, Texas Co., Wichita Falls. SECRETARY, P. F. Chapman, Box 2010, Wichita Falls.

MISSISSIPPI SECTION: Meets in Laurel, Jackson, and Natchez, Miss. CHAIRMAN, John A. Rodgers, Gulf Refining Co., Lumberton, Miss. SECRETARY, Paul Tsimortos, Gulf Refining Co., Lumberton.

OKLAHOMA CITY SECTION: Meets at noon third Thursday each month in Oklahoma City. CHAIRMAN, R. K. McIvor, Sohio Petroleum Co., Oklahoma City. SECRETARY, W. C. Pearson, Stanolind Oil & Gas Co., Oklahoma City.

PACIFIC PETROLEUM CHAPTER: Meets in Los Angeles. CHAIRMAN, Milton E. Loy, Schlumberger Well Surveying Corp., Los Angeles. SECRETARY, J. A. Klotz, California Research Corp., La Habra, Calif.

PERMIAN BASIN SECTION: Meets third Monday each month in Midland or Odessa, Tex. CHAIRMAN, J. C. Blackwood, Amerada Petroleum Corp., Midland. SECRETARY, Maurice Lewis, Jr., British-American Oil Co., Midland.

SAN JOAQUIN VALLEY SECTION: Meets first Tuesday alternate months (February-December) in Bakersfield, Calif. CHAIRMAN, Harry D. Campbell, Franko Western Oil Co., Bakersfield. SECRETARY, C. A. Davis, Richfield Oil Corp., Bakersfield.

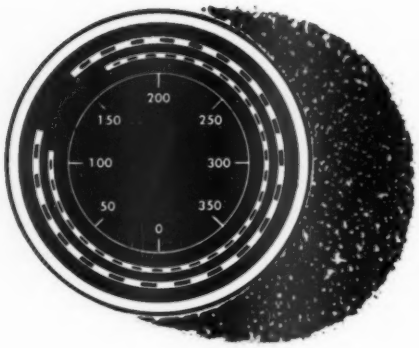
SOUTH PLAINS SECTION: Meets third Thursday each month in Lubbock, Tex. CHAIRMAN, J. W. Brown, Stanolind Oil & Gas Co., Brownfield, Tex. SECRETARY, J. B. Livingston, Halliburton Oil Well Cementing Co., Lubbock.

SOUTHWEST TEXAS SECTION: Meets third Wednesday each month in Corpus Christi. (No meetings in July, August, December.) CHAIRMAN, Chester L. Wheless, La Gloria Corp. Robert R. Wallace, Seaboard, Corpus Christi.

WEST CENTRAL TEXAS SECTION: Meets third Wednesday each month in Abilene. CHAIRMAN, J. L. Coulson, Warren Petroleum Corp., Abilene. SECRETARY, J. E. Russell, Reddin Operators Comm., Abilene.

WYOMING SECTION: Meets in alternate months in Casper. CHAIRMAN, M. O. Hegglund, Stanolind Oil & Gas Co., Casper. SECRETARY, R. N. Freeling, Texas Co., Casper.

If there are additions or corrections to be made for the 1954 local section list, please notify the AIME Petroleum Branch office.



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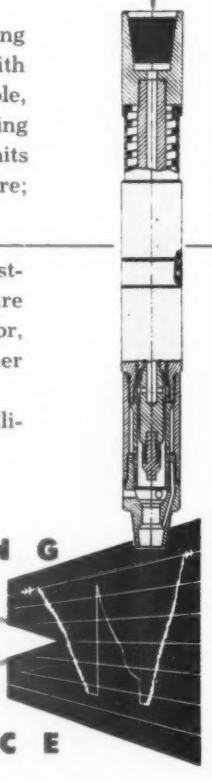

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AIME Officers Slate For 1954 Elected

The AIME Board of Directors announces the election of a slate of officers for 1954 headed by H. DeWitt Smith, president-elect. Others who will take office Feb. 16 are: T. B. Counselman and Harold Decker, vice-presidents; Ralph E. Kirk, Carleton C. Long, P. J. Shenon, George Dub, Earl R. Marble, and E. C. Babson, directors for a three-year term.

Directors ex-officio to serve one-year terms as division chairmen are: J. R. Van Pelt, MIED; J. H. Scarff, IMD; P. T. Stroup, EMD; John R. McMillan, PD; R. C. Stephenson, Ind. Min. D.: M. D. Cooper, CD; J. S. Marsh, I&SD; J. D. Forrester, MGGD; S. D. Michealson, MBD, and J. K. Richardson, MED.

Leo F. Reinartz, currently president-elect, will take office as 1954 president Feb. 16. One other director is to be named for a one-year term.

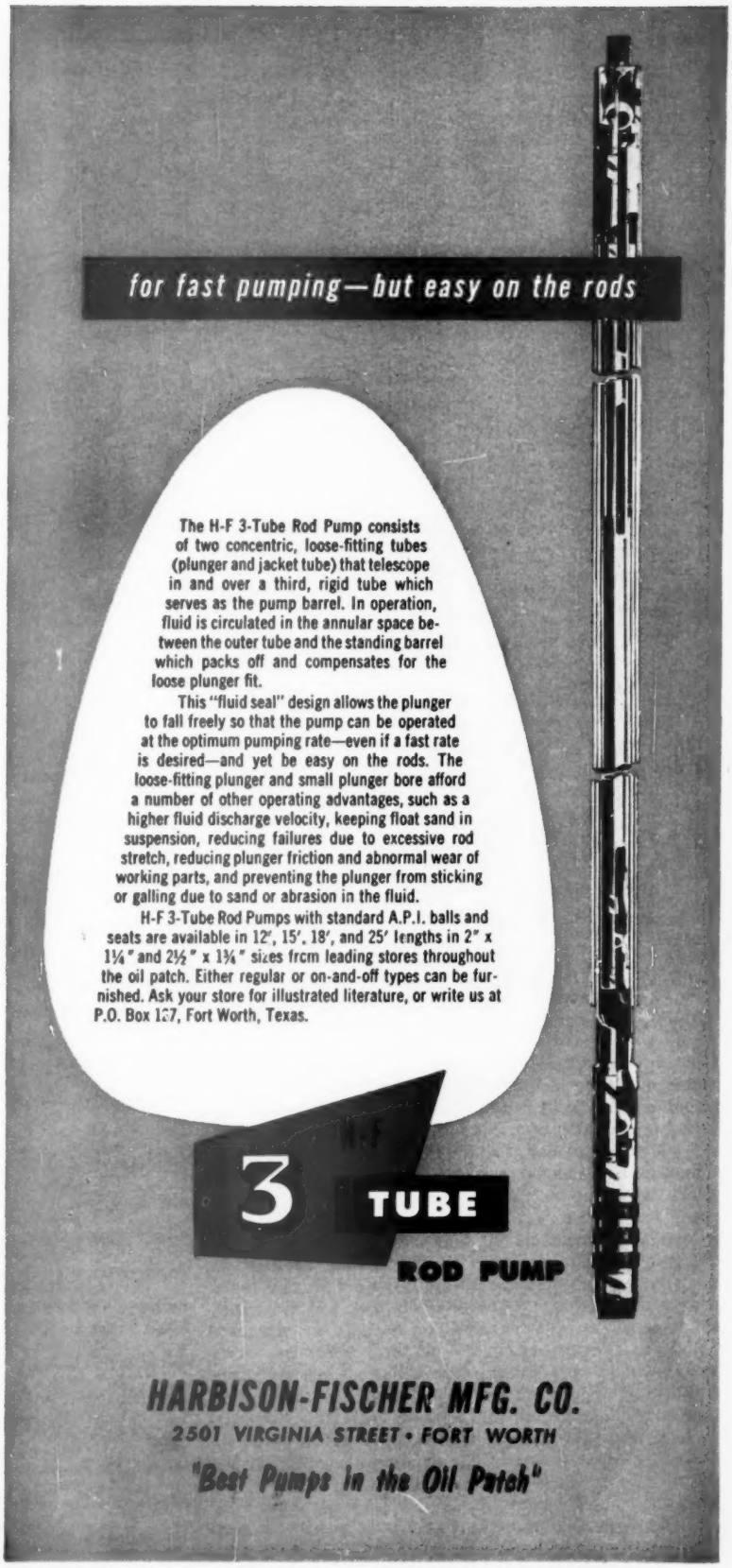
Directors Vote to Permit Overlay of Local Sections

The AIME Board of Directors has voted to permit local sections to "overlay" in some cases. This change will allow organization of two or more local sections in one geographical area provided, in the opinion of the Board, they will serve a useful purpose and increase service to members.

To make this change in the by-laws, the Board voted to delete the following words from Art. XI, Sec. 3: "... only one Section shall be authorized in any one locality and district and ..."

Monthly News Letter by Pelton Available Gratis Again in '54

Again in 1954 the Pelton News Letter is available to oil company personnel and others interested. The News Letter is "educational, containing no attempt to sell products," according to the Oil Industry Machinery Division of Pelton Water Wheel Co. Principles of operation in long-stroke pumping and service problems are dealt with in the monthly publication.


for fast pumping—but easy on the rods
The H-F 3-Tube Rod Pump consists of two concentric, loose-fitting tubes (plunger and jacket tube) that telescope in and over a third, rigid tube which serves as the pump barrel. In operation, fluid is circulated in the annular space between the outer tube and the standing barrel which packs off and compensates for the loose plunger fit.
This "fluid seal" design allows the plunger to fall freely so that the pump can be operated at the optimum pumping rate—even if a fast rate is desired—and yet be easy on the rods. The loose-fitting plunger and small plunger bore afford a number of other operating advantages, such as a higher fluid discharge velocity, keeping float sand in suspension, reducing failures due to excessive rod stretch, reducing plunger friction and abnormal wear of working parts, and preventing the plunger from sticking or galling due to sand or abrasion in the fluid.
H-F 3-Tube Rod Pumps with standard A.P.I. balls and seats are available in 12', 15', 18', and 25' lengths in 2" x 1¼" and 2½" x 1¾" sizes from leading stores throughout the oil patch. Either regular or on-and-off types can be furnished. Ask your store for illustrated literature, or write us at P.O. Box 137, Fort Worth, Texas.
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"Best Pumps in the Oil Patch"

Crude Oil Value

(Continued from Page 11)

neighborhood of 30 to 40 cents per barrel. A study in California showed that over 56 per cent of the wells cost between $7 and $12 per day to operate, while 13 per cent cost $20 or more. The majority of the latter are in unit operations.

Manufacturing costs refer to the gasoline plant costs, and can vary over so great a range (2 cents to $1 per barrel) that it is necessary to have data on the particular conditions to be considered. A representative figure might be five to 12 cents per barrel.

Ad valorem or *mineral taxes* are county taxes levied by the tax accessor and will range from a few cents to as high as 55 cents per barrel produced. The trend with time is, in almost all cases, toward an increase.

General expense costs are head office charges, such as legal expense, accounting, purchasing and management, which are realistically handled as a charge against production.

TOTAL COSTS

Operating income, which is the difference between the gross income and the total operating costs, is not profit in the true sense. There are other costs that reduce operating profit, such as exploration costs and income tax. These costs are not considered in this discussion.

Present worth is a discount factor applied to the operating income to take care of the future worth of a dollar. This is merely the cost of money. In view of current interest charges, five per cent to possibly seven per cent could be defended as reasonable. In the illustration given the present worth factor corresponds to five per cent (converted semi-annually) for 15 years. The choice of a high rate of interest such as 10 per cent will result in about one-half the present worth that a choice of four per cent would give if the production is projected to a life of 25 years. A discount factor should not be used to cover such items as hazard and inability to estimate reserves. ★ ★ ★

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348-G

DEVELOPMENT OF AN UNDERGROUND HEAT WAVE FOR OIL RECOVERY

B. F. Grant, S. E. Szasz | *Sinclair Research Laboratories, Tulsa, Oklahoma*

Studying new means of increasing the ultimate recovery of crude oil from an underground reservoir, a practicable approach appears to lie in the application of heat by generation and propagation of a combustion-supported heat wave within the reservoir rock. Field experiments to test this concept have been conducted for over five years in the Delaware-Childers field, Nowata County, Okla. One well pattern, an inverted seven spot, has been operated for the past two years with approximately 40 billion Btu generated within the Bartlesville sand reservoir by the moving combustion wave. The successive steps of firing an injection well bore, transferring combustion to the reservoir rock and the subsequent propagation of the combustion by cold gas injection are outlined. Present extent of the heat wave has been approximated by core drilling within the original well pattern. Although the overall recovery efficiency of the process cannot be evaluated until the wave reaches the producing wells some two years hence, the "banking" of oil ahead of the wave has been shown by the exploratory coring. Experience to date definitely has demonstrated the feasibility of propagating a combustion-supported heat wave through a porous and permeable reservoir rock. ★ ★ ★

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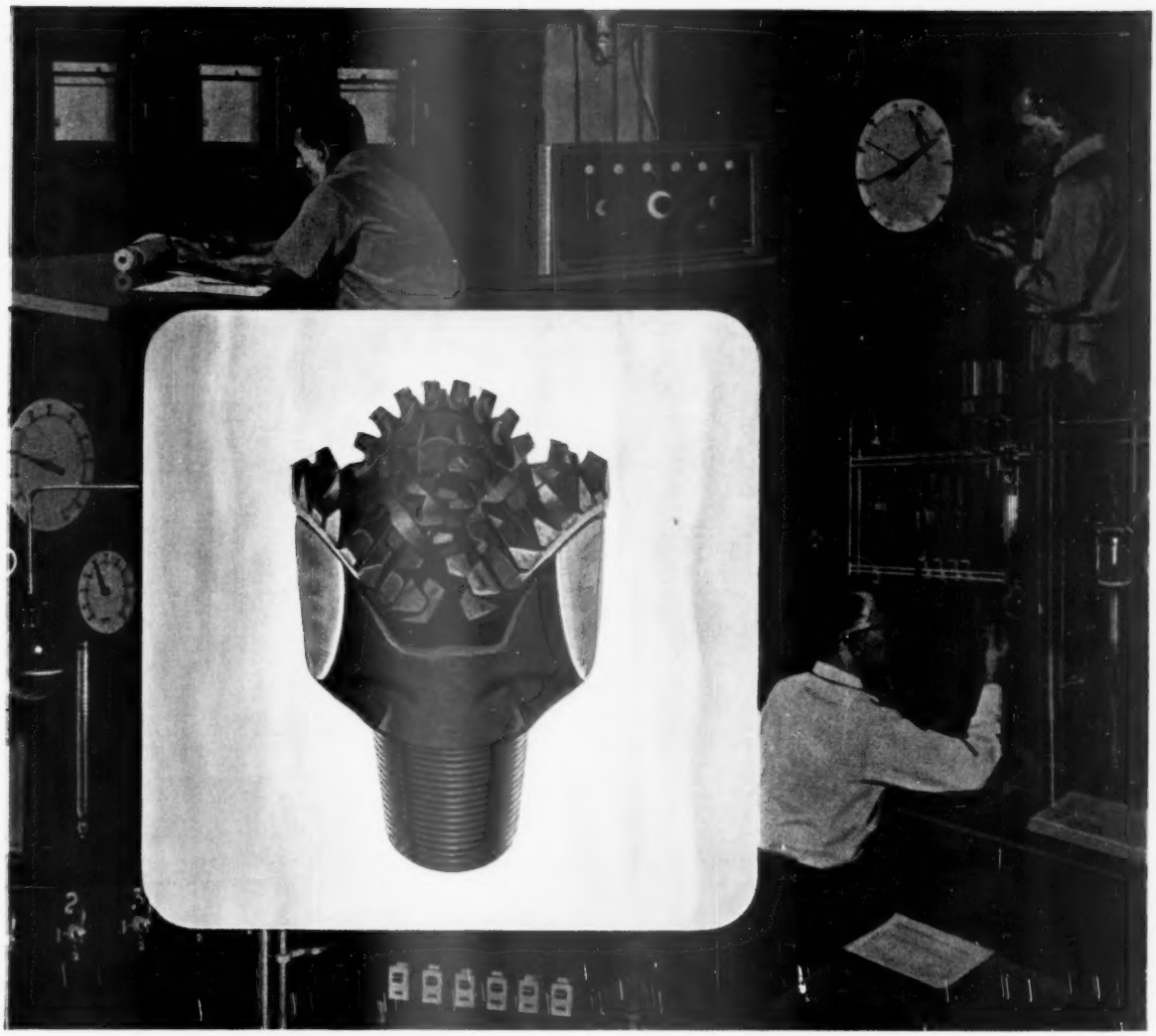

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